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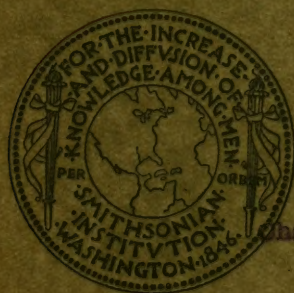
THE MINERAL INDUSTRIES OF
THE UNITED STATES

THE ENERGY RESOURCES OF THE
UNITED STATES: A FIELD FOR
RECONSTRUCTION

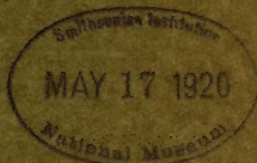
By

CHESTER G. GILBERT AND JOSEPH E. POGUE

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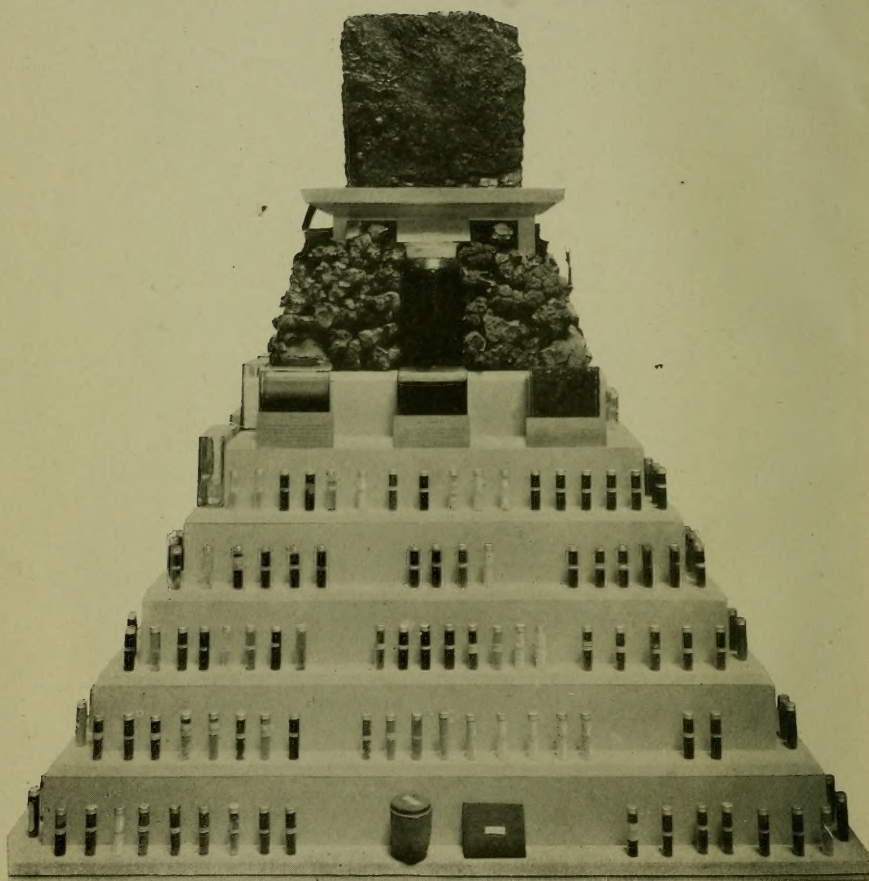


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1919



COAL AND SOME OF ITS PRODUCTS.

Photograph of model in the Division of Mineral Technology, United States National Museum.

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ISSUED MAY 15 1919



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ADVERTISEMENT.

The scientific publications of the United States National Museum consist of two series, the *Proceedings* and the *Bulletins*.

The *Proceedings*, the first volume of which was issued in 1878, are intended primarily as a medium for the publication of original, and usually brief, papers based on the collections of the National Museum, presenting newly acquired facts in zoology, geology, and anthropology, including descriptions of new forms of animals, and revisions of limited groups. One or two volumes are issued annually and distributed to libraries and scientific organizations. A limited number of copies of each paper, in pamphlet form, is distributed to specialists and others interested in the different subjects, as soon as printed. The date of publication is recorded in the tables of contents of the volumes.

The *Bulletins*, the first of which was issued in 1875, consist of a series of separate publications comprising chiefly monographs of large zoological groups and other general systematic treatises (occasionally in several volumes), faunal works, reports of expeditions, and catalogues of type-specimens, special collections, etc. The majority of the volumes are octavos, but a quarto size has been adopted in a few instances in which large plates were regarded as indispensable.

Since 1902 a series of octavo volumes containing papers relating to the botanical collections of the Museum, and known as the *Contributions from the National Herbarium*, has been published as bulletins.

The present work forms No. 102, volume 1, of the *Bulletin* series.

WILLIAM DE C. RAVENEL,

*Administrative Assistant to the Secretary,
in charge of the United States National Museum.*

WASHINGTON, D. C., April 5, 1919.

FOREWORD.

Mineral resources are coming more and more into prominence as the basis upon which modern advance is built. Their adequate development is a matter of the first importance and public opinion will be called upon in increasing measure to shape the course of advance in this fundamental field. As the general subject is not one of popular experience, this series of papers is under preparation for the purpose of interpreting in nontechnical language the significant aspects of each resource of mineral origin, in anticipation of a growing demand for concise summations of technical knowledge in a form adapted to current use.

The two most important resource problems facing this country to-day concern the supply of energy (fuel and power) which underlies the employment of all raw materials, and the supply of fertilizers, which conditions the output and cost of food. This paper (Bulletin 102, volume 1) is designed to present a constructive analysis of the energy situation in the United States, while its successor (Bulletin 102, volume 2) will be charged with a consideration of fertilizers in their bearing upon the food supply of the Nation.

THE AUTHORS.

AUGUST 1, 1918.

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THE ENERGY RESOURCES OF THE UNITED STATES: A FIELD FOR RECONSTRUCTION.¹

By CHESTER G. GILBERT and JOSEPH E. POGUE,

Of the Division of Mineral Technology, United States National Museum.

GENERAL INTRODUCTION.

Because it seems inevitable that sooner or later the energy resources of the United States must be employed more systematically and effectively than they have been in the past, this study has been made with a view toward setting forth a working plan for bettering the situation. This is done in the belief that the sustained conduct of the war and the future welfare of the country both demand consideration and action in respect to this matter. While it is commonly known that our present utilization of fuel is wasteful, it is not generally appreciated how very serious and extensive this default has become, how many lines of progress the current practice in this field is blocking, and how distinctly and heavily the whole matter is contributing to the cost of living. While the color of sensationalism is to be deprecated, the assertion can not be avoided that this country has within its reach the means for effecting a saving in the matter of its energy supply of well over a billion dollars a year. This paper points out those means. In this one direction alone lies a gain sufficient to recoup much of the expense of the Great War.

Whatever the merits or demerits of the case may be, it is evident that this country is dependent upon an intricate interweaving of activities whereby each person is enabled to gain a livelihood by doing one thing instead of performing the whole range of activities dictated by his needs. Indeed, there is now no choice in the matter; the rapid growth of the machine technology has so increased the requirements of man and encouraged him in centralized living that the individual is no longer capable of filling his own wants. Instead, he must rely upon the modern industrial system, which is energized

¹ This paper includes much of the material presented in Parts 4, 5, and 6 of Bulletin 102 of the United States National Museum under the titles, Coal: The resource and its full utilization; Power: Its significance and needs; and Petroleum: A resource interpretation.

by mechanical power and therefore at bottom dependent upon the material sources of energy. And just as an individual charged with energy may be expected to attain success, so industrialism, to which the individual is subject, may likewise be counted on to achieve a favorable outcome, if only there arises no default in its energy supply. Industrialism, or the cooperative gaining of a livelihood as it may be termed, has become an integral part of the social order and its basic needs concern not merely industrial activities but the public interest as well.

Industry employs raw materials, power, and labor, under the guidance of technological knowledge and in response to the activating influence of business enterprise. Both industry and society, in recognition of their common interest, have devoted considerable attention to labor, technology, and business enterprise; and even of late have gone to some pains to look into the matter of raw materials, especially such as are bidding fair to run out. But the energy materials and the matter of their disposition are only to-day coming in for a share of attention as a separate item, although it is questionable whether even yet the distinctiveness of this field and the highly specialized problems it brings up are sufficiently distinguished from the general run of economic issues.

The energy resources—coal, oil, and water power—differ strikingly from the raw materials in general, although they are customarily grouped under this heading. In the first place they stand apart as possessing a unique and strongly individualized mode of geological occurrence, which causes them to yield faultily under the type of economic exploitation found expedient for the normal raw materials. And in the second place they are brought into use chiefly as a means to an end and therefore are primarily *service* materials, in contradistinction to commodity materials. Representing mechanical labor, they hold in consequence a sort of halfway place between raw materials proper and human labor.

Because these distinctions have not been broadly apprehended, and because, moreover, the course adopted offered the advantages of convenience and opportunism, the exploitation of the energy resources has been intrusted by common consent to the influence of the natural economic stimuli which activate normal industrial affairs. These stimuli, in contrast to their attainments elsewhere, have failed to create an adequate situation in this particular field, but owing to the fact that the energy materials do not carry through, so to speak, it comes about that the shortcomings of the matter do not register in their own name, but translate themselves in terms of commodity cost, transportation expense, and other objective items distributed all down the industrial line until they fall ultimately upon the shoulders of the public in disguised form. Thus the source of

the trouble is lost in a labyrinth of consequences. Hence it happens that advance in the entire field of fuel and power has been lagging far behind the march of progress, but not until the shock of war brought matters to a head has the delinquency been commonly perceived. The failure of the energy resources at a crucial moment is a measure of their arrears. Now that the results of their shortcomings are common notoriety, it becomes desirable to determine their deviations from the path of progress with a view to charting the shortest return.

The energy resources of prime importance, under present conditions, are coal, oil, and water power.¹ In all three respects the United States is more amply provided than any other nation in the world. In the production of coal and oil, she takes the lead, turning out nearly one-half of the world's quota of coal and about two-thirds of the total output of petroleum. She fails of primacy, however, in respect to developed water power. An inventory of the energy situation in the United States, reduced to a per capita basis for ready visualization, stands as follows:

Energy resources of the United States calculated to a per capita basis.^a

	Current production (1917).	Used to date.	Unused.
Coal.....	6.4 tons.....	120 tons.....	35,000 tons.
Petroleum.....	3.4 barrels.....	42 barrels.....	70 barrels.
Natural gas.....	0.3 ton coal ^b	(^c).....	(^d).....
Water power (coal equivalent).....	0.4 ton coal ^e		3.6-12 tons ^e coal per year.

^a Calculations are made on a basis of a population of 100,000,000 and the figures are given in round numbers. Data on coal and petroleum are from publications of the United States Geological Survey.

^b Rough estimate of coal equivalent. 753,000,000 M cubic feet of natural gas was consumed in 1916.

^c Natural gas has been used so wastefully in the United States that the conventional coal equivalent of the total amount used to date would give a misleading idea of the service rendered.

^d Reserve not open to close estimate, but a large fraction of the original supply is already exhausted.

^e Rough estimate of coal equivalent.

While the energy resources are used primarily for the generation of motive power, the situation is complicated by the range of lesser uses to which a considerable part of the energy is applied and by the commodity values and commodity possibilities contained in the energy materials, particularly in coal and oil. A clear comprehension of this circumstance is requisite to an understanding of the attainments and shortcomings in this field, and for this purpose the whole matter may be simplified and tabulated in a rough, generalized form, as follows:

¹ Wood, while significant, is omitted from consideration in this paper; natural gas, which for the time being enjoys quite a vogue in the United States, is strictly a part of the petroleum resource. See pages 50-53.

The principal energy materials and their main uses.

	Energy content (only small part extracted by present practice).				Commodity content (mostly unused at present).
	Power (about two-thirds of total coal and oil used for generation of power).	Heat (in part derived from power).	Light (in part derived from power).	Chemical work.	
Coal.....	Generation of steam. Generation of electricity. Manufacture of gas used in internal-combustion engine.	Domestic fuel (anthracite and bituminous coal). Gas for heating. Heat for industrial processes; nearly one-sixth of total coal used as domestic fuel.	Electricity made from coal. Gas made from coal.	Reducing action of carbon in metallurgical operations. Nearly one-sixth of total coal made into coke is for iron production.	Ammonia, benzol, and tar extracted from about one-twelfth of total bituminous coal. Used as such and starting point for manufacture of fertilizers, drugs, dyes, chemicals, and other coal products.
Petroleum...	Gasoline for motor use. Fuel-oil and crude petroleum for steam-raising. Kerosene for motor use.	Kerosene for domestic heating. Heat for industrial processes.	Kerosene for lamps. Gas and electricity made from gas oil.		Lubricating oils, benzine, vaseline, asphalt, paraffin wax, etc.
Natural gas..	Used in internal combustion engine. Used for steam raising.	Domestic heat. Industrial heat in glass making, etc.	Gas lighting.....		Lampblack.
Water power	Generation of electricity.	Domestic heating by electricity. Electric furnaces for metallurgical and chemical work.	Electric lighting.	Electrochemical manufacture. Electrometallurgical processes.	Water.

Thus each energy material is used for the generation of power, the production of heat, the furnishing of light, the accomplishment of chemical work, and the manufacture of important commodities. Although these applications are largely complementary, it has come about that the various demands are filled for the most part as independent units, without reference to the fact that the same original amount of material may be made to serve several functions as well as a single end. Accordingly one portion of our coal output is devoted to power generation, another to the production of domestic heat, a third to the manufacture of coke, a fourth to the making of city gas; one part of the petroleum supply is consumed in the crude or semi-crude condition as fuel, another part is partly refined, still another fraction is completely refined, and so on. In general, the energy material is applied to the immediate purpose at hand, with no reference to any other consideration. As a consequence of this uncoordinated use a vast excess of coal and oil is consumed above the intrinsic requirement.

Again, the energy sources, coal, oil, natural gas, and water power are to a great measure interchangeable; yet each possesses certain

individual and highly important specializations. Because of this first consideration, and without reference to the second, these four sources of energy have been exploited as competitors, the cheapest and most convenient one in any given instance being drawn upon. The lavish endowment of this country in all four respects has bountifully supported and encouraged this competition up to the present. Thus oil is used in the place of coal and water power; coal is doing its own duty and that of water power as well; natural gas is wasting in the crudest of applications. The very abundance of supplies has made it unnecessary to take thought or care in their behalf. The advantages of resource endowment favoring this country have almost completely blocked progress in the field of fuel and power.

The specific shortcomings on this score are several and register themselves under the heads of production, transportation, and utilization. An advance survey of the whole field may be given in a tabulation of the main points at issue; at the same time this will serve as a listing of the problems which the detailed matter to follow is designed to interpret. Thus:

The economic status of the principal energy resources of the United States.

	Production.	Transportation.	Utilization.
Coal.....	Overproduction. Too many mines. No storage. Improper competition. Inappropriate leasing system. Inadequate application of technology.	Undue burden upon railways due to hauling energy in bulky form. No existing common carrier system for coal-generated electricity.	Almost total waste of commodity values due to consumption of raw coal. Great loss of energy due to disorganized utilization and surplus production. Needless use in place of water power.
Petroleum....	Overproduction. Too many wells. Improper competition (more serious than with coal). Inadequate application of technology.	Satisfactory.....	Waste of commodity values due to use of crude and semicrude petroleum. Loss of energy due to forced overproduction. Needless use in place of coal and water power.
Natural gas...	Same as for petroleum.....	Satisfactory.....	Loss of energy due to forced overproduction. Needless use in place of coal.
Waterpower..	Underdeveloped..... Legal restrictions. Unsuitable financial restrictions of high money rates.	Satisfactory so far as developed.	Satisfactory so far as used.

The importance of this whole matter is difficult to measure accurately or to apprehend fully, for not only is there a tremendous loss in needless labor and needless transportation as result of the backward status of affairs, but whole fields of activity of the utmost national importance have been retarded and even inhibited, while the more limited and highly specialized resources, petroleum and natural gas, have been brought to the verge of premature depletion. Something of the meaning of the situation may be presented in summarized form in a list of the important national problems that may be solved wholly or in part through the avenue of improvement in

the development of the energy resources of the country. These include such fundamental issues as the problem of transportation, of national economic policy, of national industrial development, of national defense, of food supply, of electrochemical and electrometallurgical developments, of the smoke nuisance, of the domestic-fuel supply, of industrial emigration, of petroleum exhaustion, of the gasoline supply, and of the high cost of living.

The energy resource field in its entirety, therefore, is of prime importance, not only because of its size and scope, but also by virtue of its success in retarding and blocking many radiating activities of far-reaching consequence. It is also, by the same token, complex and subtle, with its true meaning hidden by manifold details and the strong color of technical surroundings. It is scarcely possible to present such a subject so that the matter will be easy reading, but the attempt is made to show a clear and concise perspective, divorced so far as possible from technicalities and designed with the interest of the average reader, rather than the expert, in mind. To this end the theme is broken into three parts. The first has to do with coal as it presents itself to the average householder in the guise of domestic fuel; the second deals with petroleum with particular reference to its familiar product, gasoline; the third concerns itself with power, and therefore takes up both coal and water power from this common view. The various details will fall into place in this general scheme, while the conclusion will draw out the main issues and present a plan for attacking the problem of fuel and power in its entirety.

PART I.

DOMESTIC FUEL.

INTRODUCTION.

In spite of ample supplies in the ground, coal inadequately meets its obligations because of the competitive manner in which it is mined, the unnecessary extent to which it is transported, and the improper way in which it is used. The first has caused tremendous waste, the results of which will be felt heavily in the near future; the second has caused a coal shortage during the war and promises a repetition at every coming period of sudden industrial expansion; the third has imposed an excessive burden of cost upon the public. To prevent waste, to circumvent shortage, and to lower cost, changes in our system of coal economics are necessary. These changes must be determined by coal itself—by the nature of its geographic distribution, geologic occurrence, mining technology, and chemical composition. It is the purpose of this study to draw from the considerations enumerated—from an analysis of the resource—an expression of the directions which these changes should take. As the most significant deficiencies are inherent in the utilization of coal, the subject will be approached from that point of view.

THE PROBLEM OF SMOKELESS DOMESTIC FUEL.

The United States in 1917 produced in round numbers 640 million tons of coal. About one-seventh of this, or 90 million tons, was anthracite, while the rest was bituminous coal of various grades. The anthracite came from a small area of less than 500 square miles in Pennsylvania; the bituminous supply, from 30 States, with Pennsylvania, West Virginia, Illinois, and Ohio contributing about three-fourths of the total. Anthracite is hard coal, of uniformly high heating value, and burns without smoke; it is relatively costly to mine and prepare; it is regarded as the ideal fuel for the American home. Bituminous coal is soft coal, of slightly lower thermal value in the raw state as compared with anthracite,¹ and burns with the production of black smoke; it is cheaper to mine and to prepare than anthracite; it constitutes the dominant fuel dependency of American

¹ True in the average only; the highest-rank bituminous coal has a heating value greater than that of anthracite.

industry and commerce, and is used in American homes that can not afford anthracite. Vast quantities of coal lower in grade than bituminous, such as lignite and peat,¹ occur in many parts of the United States, but these as yet are practically untouched.

Coal as now used fulfills three distinct and unrelated functions. It furnishes industrial power, material for the manufacture of coal products, and domestic heat.² About two-thirds of the coal consumed in the United States goes into the production of power which is divided almost equally between the industries and the transportation systems; about one-sixth is used as a raw material for making substances employed industrially, such as metallurgical coke, upon which the iron industry depends, and gas, nitrogen compounds, benzol,³ tar, and coal-tar products. One-sixth approximately is employed for heating homes and other buildings. It will be observed, then, that the combined industrial requirements outweigh the needs of the home five to one.

This threefold function of coal involves the element of competition, which is latent in normal times, but becomes effective in periods of stress. War conditions in America developed in acute form the inevitable consequence of this competitive tendency, a shortage of fuel for domestic heating.⁴ Industrial users of coal are strong and preponderant; they can meet a growing cost by passing it on to the consuming public in the form of higher prices; and in cases of shortage they are normally given precedence in distribution. Domestic users of coal, on the contrary, are scattered and weak; in general they must accept what is left after the wants of industry are satisfied. The home, therefore, is forced to pay a price developed by the industrial demand, or else, if the price be artificially fixed, suffer more than its relative share of the shortage which the expanded demands of industry create. This condition was not peculiar to the war situation, though never before, of course, so gravely manifest; it is inherent in our present system of fuel utilization, which if unchanged may be expected to display a repetition during every future period of industrial quickening. Moreover, the growth of industrialism, by increasing the industrial consumption in respect to the domestic, will serve to make the danger progressively more serious.

The competitive tendency that now obtains between the three main uses of coal is not justifiable on the basis of the character of coal itself. On the contrary, these functions, at present antagonistic,

¹ Peat is not strictly a coal in the commercial sense, though it represents one of the first stages in coal formation.

² Coal, of course, is used for other specific purposes, but these are of secondary importance.

³ Benzol is the light oil often included in the term coal-tar.

⁴ This shortage, indeed, has been so great as to extend into industry also.

are fundamentally complementary, and they can be made so in practice to their common advantage, in respect both to yielding cheaper products to all interests as well as to imparting a stability and elasticity to the supply that will better enable it to weather periods of stress. In the ideal utilization of coal, the domestic and commodity uses will be completely complementary, while the power use will supplement the other two. Each will benefit from the others, and no one can be adequately developed without the participation of the other two. The means whereby this advantageous cooperation may be effected are feasible and within the reach of an immediate start toward realization.

Even with the utmost accomplishment in the direction of full, coordinated utilization of coal, however, there will still remain the dominant claim of power generation, involving by its size an undue tax upon the transportation facilities of the country. This persisting characteristic of present usage, with all its potency for evil consequences, can be alleviated through the development of a power resource more mobile than coal, which will relieve the railroads of part of their coal-hauling responsibility. Such a resource is at hand in the form of hydroelectric power, as yet hardly touched in this country; and the bearing upon the coal situation, and especially upon its transportation aspects, that a proper utilization of this source of power would have, is treated in Part 3 of this paper.¹ The adequate development of water-power would not only relieve an unnecessary reliance upon our transportation systems, but it would also reduce the power use of coal to a portion more amenable to smooth coordination with the parts employed in the coal-products industries and the home.

The point of logical attack upon the coal problem, then, centers in the home, for here lies the greatest weakness in the present system of coal utilization. It is in the home that conditions are the most discomfiting in times of stress, that trouble, whether it be of high price or actual shortage, has the least chance of remedy by industrial enterprise. The problem, too, finds its closest contact with the individual in the affairs of everyday life; and its complexities may be reduced to their simplest expression in terms of this point of view. But it should be clear that although the line of advance may start with changes that benefit the individual user of coal, the course of progress brings no less advantage to the field of industry. The whole matter, however, concerns the individual directly and foremost; he will be the gainer or loser according to whether or not he sees fit to interest himself in the means for effecting the progress

¹ See page 103.

not merely needed, but absolutely essential, to the well-being of the immediate future.

Approaching the coal problem from the point of view of the domestic user, we find that the homes of the country are insistent upon anthracite, in so far as its use is not precluded by expense or excessive distance from the area of production in Pennsylvania. Thus the entire northeastern part of the country is entirely, and contiguous territory as far west as St. Paul and as far south as Atlanta, is partly, dependent upon what is popularly termed hard coal. As is well known, this is due to the twofold fact that anthracite is clean, both in handling and in its smokeless combustion, and its heating effect is uniform and high. It is needless to add that the dependency developed because a coal resource of this type was present in a populous and accessible part of the country.

But anthracite is a luxury. It combines refinements of quality with limitations of supply—the characteristics of every luxury. Its cost of production is approximately twice that of bituminous coal;¹ it emanates from one region only, a district of heavy freights; it has no capability toward yielding by-products to modify its cost; besides, a big fraction of the available supply is already exhausted. Its domestic use may be continued as a luxury, but anthracite must be dismissed as not equal, or adapted, to the task of supplying the American home.

The home, therefore, independently of its wishes in the matter, must turn to bituminous coal for its fuel dependency. There is no alternative. Already this has happened to a partial extent; war conditions have accelerated the change; the future demands it more completely. The advantages of bituminous coal are well known—its relative cheapness, its wide distribution, its ample reserves,² the possibility of improved utilization. But there is one grave objection to the use of bituminous coal—its dirtiness. This is a valid objection. Burned in the raw condition, it gives off dense, black smoke which dirties the home, pollutes the atmosphere, and becomes the implacable enemy of civic betterment as well as a menace to the health of the city dweller. Such a result can not be countenanced.³ It so happens, however, that smoke represents the most concentrated value in bituminous coal. If we can extract this value and use it toward reducing the cost of fuel, at the same time making a smoke-

¹ Responsible for this is a complicated geological occurrence, involving folded strata, depth, water, and association with thin seams of slate, as contrasted with the average flat, close-to-the-surface beds of bituminous coal.

² Less than 1 per cent of the bituminous coal of the country has been used.

³ Furnaces which consume the smoke are in use, but they have made no impression on the general situation; they can not meet universal acceptance, because they throw the smoke on the debit side of the balance sheet, instead of into its true position, the credit side.

PERFUMES

BENZOIC ACID

PERFUMES

PITCH COKE

FUEL

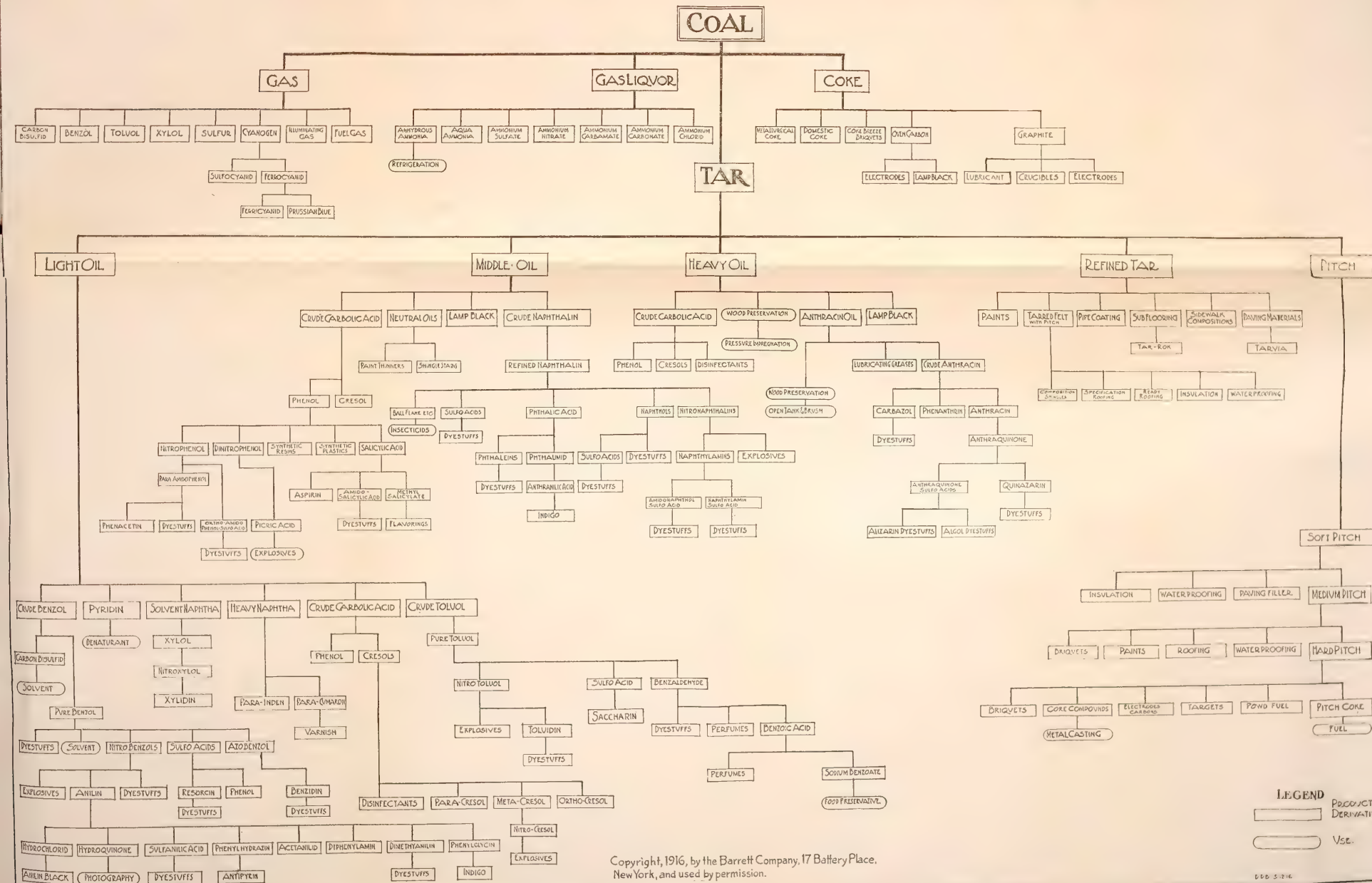
END

PRODUCT OR
DERIVATIVE.

USE.

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COAL



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less product for heating use, the sole objection will be turned into an advantage, and the domestic fuel problem will be solved.

In 1915, before the price of coal was enhanced by war conditions, the average value of bituminous coal at the mine was \$1.13 a ton. By way of contrast, we may tabulate the latent values contained in an average ton of raw coal, giving the figures in round numbers and basing the calculations on prices prevailing in 1915.

Balance sheet showing contrast between value of 1 ton of bituminous coal at mine and value of products which it contains, based on conditions prevailing in 1915. The contrast is greater to-day.

	Value at mine, 1915.	Quantity.	Value at point of pro- duction, 1915.
1 ton (2,000 pounds) bituminous coal contains	\$1.13	1,500 pounds smokeless fuel..... 10,000 cubic feet gas, at 90 cents per 1,000.. 22 pounds ammonium sulphate, at 2.8 cents.. 2½ gallons benzol, at 30 cents..... 9 gallons tar, at 2.6 cents.....	a \$5.00 b 9.00 c .61 c .75 c .23
Total.....	d 1.13		15.59

a Figure based upon approximate selling price of anthracite.

b Figure based upon average price of city gas.

c These figures would be much higher if an adequate coal-products industry were in existence.

d This figure shows clearly that lowering the cost of production can not be expected to lower the price of coal. Even if the cost of production were eliminated, the price of coal would merely be a dollar less.

Obviously, there should be a way for the home to get its fuel more cheaply than it has, when a ton of coal selling at about \$1 at the mine contains about \$14 worth of commodities useful to society.

One answer to how these values may be got in full from coal lies in the development of artificial anthracite. The accomplishment depends merely upon the establishment of a process which will isolate the solid-fuel portion of bituminous coal in the form of a substance equivalent to anthracite, and produce from the remainder a number of products whose value could be made to more than carry the expense of the operation. Nature has pointed the way with natural anthracite, which was originally bituminous coal, but has subsequently, under the stress of geological evolution, lost its volatile portions, forced out by the action of pressure and heat. It is merely a matter of accomplishing a similar result by artificial means, but with the important advantage that while nature dissipated the volatile constituents and produced only one end product, man could catch these values and turn them to his advantage. There are no insuperable difficulties in the way of such an accomplishment. Several processes capable of this attainment are already in course of development, although comparatively little organized research has been directed to the problem. An intensive attack, such as the importance of the matter deserves, would unquestionably yield an entirely satisfactory procedure. The problem, in reality, is rather one

of economics than of technology. When the need for artificial anthracite is generally appreciated, a suitable process for its manufacture will be forthcoming.¹

Granted the necessity for a smokeless fuel other than anthracite and recognizing that it is chemically feasible to make such a product from bituminous coal, we may examine the existing economic practice that bears on this matter, with a view to ascertaining at what place, if any, a process as outlined above may be introduced and placed on a working commercial basis.

THE COKE INDUSTRY AND ITS BEARING ON DOMESTIC FUEL.

We naturally turn first to the coke industry, for here the greatest progress in coal utilization has been attained, and besides coke has already been used to a limited extent for domestic heating. The coke industry consumes nearly one-sixth of our bituminous coal, and has as its immediate purpose the production of coke, a substance required by the iron industry, which absorbs most of the output.²

Coke is made by heating certain classes of bituminous coal at high temperatures, with the production of a hard, porous residue, composed essentially of carbon.³ Two methods of manufacture are in general commercial use. One employs beehive ovens, so called from the shape of early types; the other makes use of retort ovens, which are usually long and narrow and assembled in batteries. The latter are appropriately termed by-product ovens.

The beehive oven delivers a product well suited to metallurgical use, but the process is objectionable because of the waste involved. It not only fails to yield the maximum of coke, but it effects no recovery of other valuable constituents. The products lost represent a measurable waste in terms of dollars, but they carry greater significance as being the raw materials upon which could be built an adequate manufacture of fertilizers, dyes, drugs, and explosives. It is a strange anomaly that the beehive oven has been made necessary by American economic policy.

The by-product oven receives raw bituminous coal and subjects it to destructive distillation. This process consumes none of the coal, but breaks it up into five components—coke, gas, ammonia, benzol, and tar—of which coke is the main product, while the other four constitute by-products. About half of the gas produced is used to supply the heat essential to the operation; the by-products are partly

¹ When a specific industry is in need of a process to attain a certain end, it goes ahead and perfects the process. No individual industry is in need of artificial anthracite, but public interest demands it. The responsibility is obvious; it falls upon the public.

² From 1 to 1½ tons of coke go into the production of 1 ton of iron, so that the coke industry is essential to the iron industry. Coke also enters into a number of other metallurgical processes.

³ Much of the bituminous coal in the United States is not suited for the manufacture of coke because it yields a product not physically adapted to metallurgical use.

or wholly recovered according to the details of the practice. Where the by-products are wholly recovered, no part of the coal is wasted. In round numbers, 1 ton of bituminous coal yields 1,440 pounds of coke, 10,000 cubic feet of gas, 22 pounds of ammonium sulphate,¹ 2½ gallons of crude benzol, and 9 gallons of tar.² Half of the gas is available for use as fuel or in lighting; the ammonium sulphate is a valuable fertilizer; benzol is an excellent motor fuel, a substitute for gasoline; tar is a waterproofing material used for making roofing and for dressing roads.

These four first-products have an unlimited field of usefulness as such. In addition, three of them represent raw materials upon which important fields of present industry are dependent and upon which, if bountifully supplied, new industrial activities of far-reaching consequences can be reared. The ammonia, recovered as such, instead of in the form of ammonium sulphate, forms the basis of modern refrigeration and is used for making explosives and chemicals. Benzol is a mixture of substances, including the deadly toluol, which can be made to yield explosives, dyes, drugs, medicines, solvents, photographic developers, and other chemicals. Tar, likewise, yields a 10 per cent fraction which may be turned into explosives, disinfectants, dyes, drugs, and other products. Benzol and tar, in short, are the basis of the coal-tar industry, inadequately developed as yet in America—an industry which Germany has intensively cultivated to an advantage now well known.

The by-product oven is complicated and costly to install³ and to operate. Like the beehive oven, its prime purpose is to deliver coke, but it can compete with the beehive only when the by-products can be disposed of with sufficient advantage to cover the greater expense of the by-product practice and contribute a margin of incentive. The development of by-product coking in the United States has been slow, considering the social and national importance of the possibilities inherent in this activity. At the beginning of 1918, the beehive oven still turned out over half of the coke produced, although war conditions and war demands have given a strong impetus to by-product coke development.

The reasons for the lagging growth of by-product coking in America are clear and specific. There has not been a sufficient demand for all five of the products, due to inadequate industrial utilization of gas and the practical lack of a coal-tar industry.⁴ Our economic adjustment gave a stable demand for only two of the products, coke and

¹ The solid form in which much of the ammonia is recovered.

² These figures are approximate. They vary with practice and grade of coal.

³ The cost of constructing a modern by-product coke oven plant of minimum commercial size in normal times would be nearly a million dollars; under present conditions, more than twice that amount.

⁴ Also the apparent abundance of gasoline put no demand upon benzol as a motor fuel, contrary to the experience of European countries.

ammonia. The gas had a varying value from a product representing the chief source of revenue in some instances down to one giving returns too small to justify its storage.¹ The benzol, a few years back, was not even recovered, so lacking was any demand for it.² The tar, like the gas, had a considerable though low range in value, but until a few years ago it was scarcely profitable to extract it.

The consequences of inadequate coal-products development in the United States have been serious, in some respects critical. Here falls entire responsibility for recent shortages in explosives of certain types, as well as in dyestuffs, and a variety of drugs and chemicals; partial responsibility for the high cost and inadequate supply of nitrogen compounds and gasoline; and even a little of the blame for the transportation congestion of 1917-18, which industrial coal-gas utilization could have alleviated in some measure. These considerations are apart from wasted materials and wasted opportunities. The coal-products situation, indeed, represents one of the most complex, subtle, and important problems in the whole field of industry to-day; and this is true not only in respect to present conditions, but also as regards the trend of future industrial growth to a degree difficult of full appreciation. The failure of Great Britain to sense its importance before the outbreak of the European war came desperately near causing her defeat during the first few months of hostilities through a lack of toluol; the situation was only saved by the happy chance that the British gas industry was developed with by-product recovery, and by straining met the emergency. A similar omission on the part of the United States is responsible for some of our recent embarrassments. A failure to remedy the situation will place this country at an unfortunate disadvantage in the future. It seems remarkable that a single, partly developed unit of industry can have such a vital and far-reaching bearing on the well-being of the entire nation, but such is unequivocally true of coal products. That fact can not be expressed too plainly or in terms too strong.

To build a proper coal-products industry, even within the limits set by the coke needs of the iron industry, will require the establishment of a steady demand for the four by-products—gas, ammonia, benzol, tar—which will give them a commercial value in keeping with their real worth. This, in turn, will depend upon an enlarged utilization of gas for fuel purposes, and the growth of a substantial coal-tar industry that to the certain values of the primary products will add indefinite constructive possibilities of increased values in a field already advanced to the point where warfare, textiles, and chemical manufacture are utterly dependent upon it. The whole accom-

¹ It is significant that in 1915 the average cost of city gas was 91 cents per 1,000 cubic feet, while the average cost of gas from by-product coke ovens was 10 cents.

² And benzol contains toluol, upon an adequate supply of which modern warfare is absolutely dependent.

plishment waits upon a constructive economic policy which recognizes in true perspective the pivotal importance of coal products.

The significance of the coal-products field and the need for its adequate expansion has been dwelt upon at length, because this matter concerns not merely the portion of bituminous coal made into coke, but bears with peculiar meaning upon the utilization of the much larger portion consumed as fuel.

Having examined the coke industry and observed its main purpose, the production of metallurgical coke, and the incidental recovery of by-products on the part of about half of the activity, we may ask if this industry can not extend its scope so as to produce a surplus of coke which may be applied to fuel use. The answer is in the negative. Coke, being designed for another purpose, is not a satisfactory fuel. While smokeless in combustion, its cellular structure gives it an intensity of combustion and susceptibility to chill that renders its control troublesome. Even a radical change in furnace design can not be expected to overcome this difficulty. Moreover, the coke industry is centralized, subject to marked fluctuations according to the demand for iron, and has not yet succeeded in modernizing more than half of its practice. Besides, its by-product manufacture is complicated and costly. Metallurgical coke, then, must be dismissed as an impracticable general-service fuel. The by-product coking practice, however, illustrates the principle of full coal-value utilization and therefore points the way toward progress in respect to fuel coal. Modified by-product plants, simpler than by-product coke ovens, producing a non-cellular carbonized residue and located near the points of utilization, represent the lesson to be drawn from the coke industry.

THE GAS INDUSTRY AND MUNICIPAL BY-PRODUCT FUEL PLANTS.

We may turn next to the gas industry to ascertain if this activity is capable of adaptation so as to contribute an adequate smokeless fuel for domestic and power consumption. This industry consists of a great number of separate plants, distributed, one or more each, among the cities of the country.¹ In the aggregate these plants consume about 1 per cent of the annual coal production of the country. Their prime purpose is to manufacture gas, and this they do without adequate regard to the complete recovery of by-products, although many plants effect a partial recovery of ammonia and tar, and some gas-house coke is put upon the market. Apart from the oil-gas plants on the Pacific coast, in which petroleum is used because of its relative cheapness in that region, the artificial gas industry of the country employs coal as its raw material.

¹ There are over 900 artificial gas plants in the United States, exclusive of by-product coke ovens.

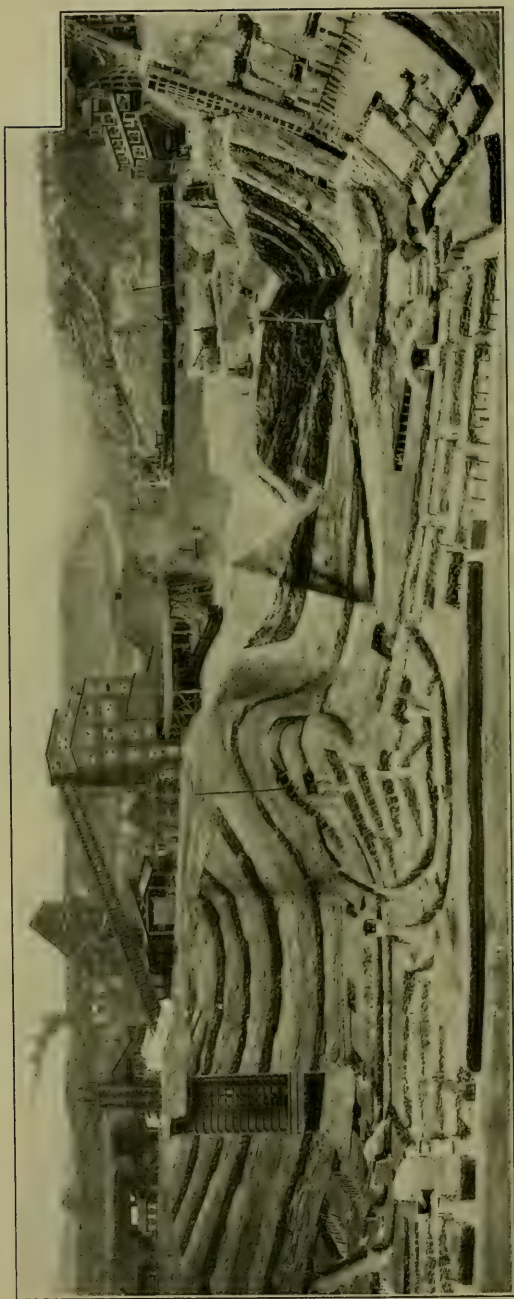
Three types of gas made from coal are in general use—coal gas, carbureted water-gas, and mixed gas. Coal gas is distilled from bituminous coal by heating the latter in retorts. Carbureted water-gas is produced as a result of the action of steam upon coke or anthracite, the nonilluminating water-gas thus produced being then “carbureted,” or enriched, by the addition of a gas of high thermal and illuminating power made from oil. Mixed gas is a mixture of coal-gas and carbureted water-gas and is supplied in many cities in the United States, the coke from the coal-gas production furnishing the basis of the water-gas manufacture.¹

The gas companies are by nature and in fact public utilities. They manufacture a necessity which does not lend itself to competition. They are private enterprises under municipal control, which is largely directed, however, to price restrictions, and is not constructive in the way of compelling advances in technical procedure. With some exceptions, the average municipal gas plant is a small and antiquated organization, both in practice and in vision, far behind present possibilities of manufacture and application.² In some cities in the United States, the gas companies are in the nature of large public-service corporations, which have made considerable advance in gas production, but nowhere is there full by-product recovery and the price of city gas is uniformly high.

Although the municipal gas plant now meets rather inadequately only a small share of the fuel needs of the community which it serves, it represents an established activity which can be converted into an organization that will supply all the fuel, whether gaseous or solid, that the community requires. The transformation may retain the gas mains and much of the other equipment of the present type of plant, but in the place of the present procedure with relative neglect of by-product recovery will be substituted a by-product system of coal distillation, producing artificial anthracite, gas, ammonia, benzol, and tar. This will mean in each city a centralized purchase and consumption of raw coal, and a centralized distribution of products. The output will be limited at first, at least, by the demand for solid fuel. A production of ample solid fuel will give an excess of gas over that now produced, which will call for an expansion in the use of gas, both in the home and in industry. Such expansion will come as a result of cheaper gas, incidental to the proposed plan of

¹ In many cities the gas plant is hampered by the imposition of a standard based on candle-power. This is a survival of the flat-flame use of gas, and now that the incandescent mantle makes heat in the flame and not artificial enrichment in the gas the true object to be sought, a calorific standard should supersede altogether an illuminating one.

² In Great Britain the gas industry is far in advance of that in the United States; allusion has already been made to the important rôle it has been able to play in that country by supplying toluol for explosive manufacture. It should be emphasized that the gas industry in the United States has been impeded by restrictions imposed by economic conditions and by the type of public control affecting its affairs and in consequence is by no means wholly responsible for such delinquencies as exist.



THE OCCURRENCE AND MINING OF ANTHRACITE COAL.

Photograph of a model. By courtesy of Howell's Microcosm.

production, together with improvements in methods of utilization; and this very expansion will cut down the use of solid fuel and thereby hasten the adjustment. The three remaining first-products, ammonia, benzol, and tar, as already pointed out, have an unlimited field of usefulness as such, even within the municipality;¹ and by shipment will contribute a supply of raw material to the needs of the coal-products industry, thus permitting and inducing this important field of endeavor to advance beyond the limits now imposed upon it by the coke industry.²

The objection may be advanced that artificial anthracite has not been perfected and placed on a commercial basis, and until such time the utilization as outlined above must wait. It is indeed true that such a process is not worked out in detail and ready to be fitted into the present gas industry, but a similar condition has been a stage in the development of practically every technological process and the recognition of the demand has created the means for its accomplishment. But even granting the objection as valid, we find that the production of artificial anthracite is only one of two solutions to the problem of developing an adequate smokeless fuel from bituminous coal. The prime idea is to separate the heat- or energy-producing portion of the coal from the constituents valuable as commodities, and dispose of the two groups to their mutual advantage. Hence if we convert the energy component entirely into gas and recover the by-products, we may accomplish our purpose without calling into service a single procedure which is not already in successful practice in other fields of industry. The municipal gas plant affords, in the second instance also, the logical point of attachment for the development. Only, in this event, in the place of artificial anthracite and gas, plus ammonia, benzol, and tar, the output would be gas entirely, with a similar production of ammonia, benzol, and tar.

The twofold possibility of advance in coal utilization brings up the relative advantage of a solid, smokeless fuel versus a gaseous fuel. Their applicability for domestic use may be examined first. Solid fuel, such as artificial anthracite, requires no change in present types of furnaces and grates; is applicable to suburban and out-lying districts not served, or servable, by pipes; and will always be in demand for open fires. Gaseous fuel, on the other hand, eliminates the factors of storage and haulage, reduces dirt, and through the automatic temperature control of gas-fired furnaces nullifies the conspicuous losses growing out of ignorance and waste in connection with

¹ Ammonia as a fertilizer, benzol as a motor fuel, and tar as a road dressing.

² It is not beyond the bounds of reason to foresee a condition whereby a householder, in the place of his ton of anthracite which he now welcomes for \$11, will receive a ton of smokeless coal without slate, a month's supply of cooking gas, 40 miles of motor fuel, enough fertilizer to start a small garden, and tar sufficient to allay the dust in front of his house—all for far less money than he now pays for inferior coal. This may appear a fanciful picture, but coal has precisely this possibility within itself.

present hand-firing. For industrial purposes, gas offers conspicuous advantages, as evidenced by the varied industrial use of natural gas in all regions where abundance of supply creates a low price.

In general, gaseous fuel is bound to increase in importance as compared to solid fuel, especially in the industries. While solid fuel lends itself to conversion into power only through the agency of the wasteful steam engine, gas may be used in the internal combustion engine, which for the same equivalent consumption delivers in general over twice the power; while for purposes of producing heat, gas presents an ease of control and a mobility of application that place it beyond comparison. Moreover, and most important of all, solid fuel has already reached a far fuller measure of development than has gas, whose utilization is still in a relatively undeveloped state. Improvements in the internal combustion engine, the gas turbine, the utilization of gas under pressure, and the application of the so-called surface method of combustion offer lines of advance that will add a growing weight of superiority to the use of gas.

For domestic purposes, however, the advantages of solid and gaseous fuel are somewhat complementary, rather than opposing, so that advances toward perfecting the two types of fuel may well be simultaneous. The successful operation of an artificial anthracite plant will demand increased utilization of gas, involving the employment of the latest advances in its application; while the operation of an enlarged municipal gas-plant, with adequate by-product recovery, however effective in the way of economical gas supply, can not be expected to replace fully, at least for some time, the need for a smokeless solid fuel. In either event, therefore, the tendency will lead toward an increased rôle for fuel gas, a trend in line with the inevitable necessity for a more mobile and more efficient source of heat and power than is afforded by solid carbon.¹

The successful instigation and operation of either of the two plans proposed will depend upon public initiative and stimulus. Neither plan may be expected to come into action under the influence of private industrial enterprise; a private organization would have no means of getting adequate returns upon the development expenditure since the benefits contemplated would accrue alike to all industrial activities as well as to the public. The first move, therefore, devolves upon the public; or at least, upon organizations representative of the public interest. The accomplishment, however, will call for a more effective administration of public utilities than has obtained in American cities in the past, and this will come only after full public realization that technical affairs must be directed by technical knowledge.²

¹ It is scarcely necessary to point out that both solid and gaseous fuel are adapted to the generation of electricity.

² See also pages 155-158.

LOW-GRADE COALS AND BY-PRODUCT PRACTICE.

Although the whole coal problem has been approached from the point of view of effecting advances in utilization that will tend primarily to the advantage of the householder, the plans outlined may be extended to meet an appreciable portion of the requirements of industry; in fact, their success even requires a certain coordination with the fuel needs of industrial activities. As already pointed out, development of artificial anthracite will give an excess of gas over present domestic wants which must be consumed, in part, in power generation now dependent upon raw coal. Artificial anthracite itself would be suitable for steam raising and therefore offer to industry the same advantages that it holds for the home, including the possibility, if fully used, of making our cities and railways completely smokeless. The adequate development of artificial anthracite, in coordination with a large coal-products industry, may be expected to create a competitor for raw coal that would gradually put it out of use; for there is no insuperable reason why the fuel portion of coal should not be widely available at less cost than raw coal. The alternate plan of complete gasification of coal, with by-product recovery as carried out in municipal public utility plants, would of course offer abundant gas for industrial use in manufacturing centers, enabling the wasteful steam engine to be replaced by the more efficient internal combustion engine; while at the mine a similar procedure, under private control, could be made to supply gas for nearby distribution or convertible at once into electrical energy, susceptible of effective transmission within a radius of two hundred miles. Electrical energy, indeed, is now being generated at the mine mouth in some of the more populous coal-mining regions, with the difference that the coal is not gasified but is used in the raw state under steam boilers; offering the objection, therefore, of inadequate recovery of energy and commodity values.

In Europe, with the necessity for economies in fuel consumption, far greater advances in the utilization of coal have been attained than in the United States. And these advances, it may be observed, are such as to lend the encouragement of successful experience to the changes in coal utilization demanded by the needs of our own situation. The status of the British gas industry has already been adverted to as higher than that of the corresponding activity in the United States; while the by-product coking of coal, as is well known, has been carried further in Germany than elsewhere, resulting in the strong position attained by that country in the manufacture of dyestuffs, chemicals, and explosives. Noteworthy progress abroad centers also around the development and use of producer gas, the

briquetting of low-grade coals, and to a limited degree around the manufacture of domestic "coke."

Producer gas is the result of the complete gasification of coal under the action of a mixture of air and steam.¹ Both high-grade and low-grade coals may be employed in its manufacture and the gas may be produced with or without the recovery of the by-products, ammonia, benzol, and tar. Most of the foreign by-products producer-plants, however, at least before the war, made adequate recovery of the ammonia only. The producer principle is not only successfully applied to central plants manufacturing gas for transmission as such or for the generation of electricity; but it is also employed in smaller and more mobile installations, known as suction plants, in which the gas-producer and gas-engine are a single unit. The suction plant, therefore, adapts raw coal to immediate use in the internal combustion engine, combining the efficiency of the latter with the mobility of the steam engine. Thus producer-gas is suitable not only for large service stations, but also for small industrial plants and even for marine engines and locomotives. The manufacture of producer-gas from coke, peat, lignite, and high-ash mine refuse has become so thoroughly established on the continent as to be a commonplace procedure. The widespread use abroad of the producer gas principle has brought into competition with high-grade coals used as such the low-grade coals and coal-like substances needed to supplement a limited fuel supply.

The briquetting of low-grade lignitic coals and coal slack has been successfully practiced in Germany and other European countries for over 30 years, thus, together with the results attained by producer gas, bringing into service types of coal largely unused in the United States. A number of special forms of fuel coke, approximating artificial anthracite, have met with some measure of success, especially in England, where they are sold under the trade names of coalite, charco, coalexld, and others.

As a war measure, the belligerent countries of Europe were forced to take radical steps in order to insure an advantageous use of their coal resources. The French and Italian Governments assumed complete control of distribution. In May, 1917, the Russian provisional Government took over the coal mines of that country for the purpose of controlling distribution and prices. Early in the war, Germany centralized the entire coal industry under Government control and a recent report states that the use of raw coal has been forbidden. In England, the coal mines are under full Government authority and in addition a board of fuel research has been established which is recognizing both the economic

¹ It is strictly speaking modified or semi water-gas, lower in calorific value than water-gas proper which is made by gasifying coke or anthracite under the action of steam.



Fig. 1.—Sketch map showing the distribution of the coal resources of the United States. Generalized from a detailed map by M. R. Campbell, the coal fields of the United States—General introduction: Professional paper 100-A, U. S. Geological Survey, 1917.

and technological sides of the problem of bettering the service obtained from coal. The steps taken by the United States are well known.¹

In view of the advances in the utilization of low-grade coals abroad, we are led to inquire as to the potentialities of similar coals in the United States, which have heretofore not been called into service because of the prevalence of more desirable grades. Low-rank coals are very abundant in this country as shown by the United States Geological Survey, whose results may be summarized and expressed in round numbers on a per capita basis, as follows:

Coal reserves of the United States calculated to a per capita basis.^a

	Now under- ground.	Mined to date.
	Tons.	Tons.
Anthracite.....	180	28
Bituminous coal.....	15,000	92
Lignitic coals ^b	20,000	(^c)

^a The calculations are made by the writers from data presented by Marius R. Campbell, *The Coal Fields of the United States: General Introduction*, Prof. Paper 100-A, U. S. Geological Survey, 1917. The figures are given in round numbers based on a population of 100,000,000.

^b Includes subbituminous coal, which is between lignite and bituminous coal in quality.

^c Practically untouched.

The deficiency of anthracite and the magnitude of lignitic coals are at once apparent. It has already been shown how the undue dependency on the small and waning anthracite reserve may be relieved by a suitable by-product utilization of bituminous coal. The further application of the same principle would likewise lend significance to our lignitic coals, tending to raise their value from little or nothing to a point justifying their adoption in the place of higher-rank coals in those regions, at least, in which lignites alone occur.² And in this connection, it should be noted that lignitic coals occur chiefly in the Dakotas, Montana, Wyoming, Colorado, Arizona, New Mexico, Texas, and Louisiana, in sections largely free from other coal resources. (See fig. 1.)

Considerable experimental work in this country has already been directed toward making lignites effective sources of heat and power. Because of their high moisture content and tendency to "slack,"

¹ The Federal Trade Commission under date of June 19, 1917, recommended to the United States Senate: "First. That the production and distribution of coal and coke be conducted through a pool in the hands of a Government agency; that the producers of various grades of fuel be paid their full cost of production plus a uniform profit per ton (with due allowance for quality of product and efficiency of service).

"Second. That the transportation agencies of the United States, both rail and water, be similarly pooled and operated on Government account, under the direction of the President, and that all such means of transportation be operated as a unit, the owning corporations being paid a just and fair compensation which would cover normal net profit, upkeep, and betterments." (S. Doc. No. 50, 65th Cong., 1st sess., Washington, 1917, pp. 20-21.)

² The subbituminous coals are now used to some extent, but inadequately.

these coals are not suitable for transportation like ordinary coal. Efforts toward burning them in powdered form, with the effect of gaseous fuel, or of compressing them into briquets have met with some success, but their greatest possibilities are afforded through complete gasification in gas producers,¹ or by carbonization with by-product recovery. The Bureau of Mines has demonstrated in respect to the last that 1 ton of air-dried lignite may be made to yield 8,000 to 10,000 cubic feet of gas, 17 pounds of ammonium sulphate, 1 gallon of oil, 50 pounds of tar, and one-half to two-thirds ton of carbon residue convertible into briquets approaching the value of anthracite.² Thus may even coals lowest in rank be raised to meet the social needs for smokeless fuel and economy.³

THE PRODUCTION OF COAL.

While the greatest improvements, with most telling consequences, are possible and necessary in the utilization of coal; the conditions of coal production are likewise not best adapted to the nature of the resource and offer opportunities for advantageous changes. Passing over anthracite, because it is not inherently a necessity and because, moreover, its production is effective both as to engineering practice and coordination of operations, we find that the mining of bituminous coal is so widely scattered and loosely cooperative that the aggregated activities are to be looked upon as an "industry" only in respect to their common purpose.⁴ The country's most basic resource, indeed, is produced through the medium of a thousand disintegrated units, working without concert and under conditions of destructive competition.

Bituminous coal mining as an industry is beset by conditions which are the occasion of present wastefulness and the justification

¹ A few producer-gas plants are in service in the lignite areas. A specific instance of the applicability of suction gas-producers would be in connection with the motor boats in service along the Alaskan coast which now use gasoline brought from California, but instead might employ the low-grade coals so plentiful in parts of the Alaskan coastal region. The present attempts at fuel economy seem superficial, when the real points of wastefulness are held in mind.

² "There seems little doubt but that the briquetting and the production of gas from lignite can in the near future be put on a commercially satisfactory basis." Babcock, E. J., *Economic Methods of Utilizing Western Lignites*: Bull. 89, Bureau of Mines, 1915, p. 65.

³ We may profit by the words of a distinguished British engineer and chemist, the late V. B. Lewes, who writes of the coal of England:

"Among the factors that lead to the commercial supremacy of a country by far the most important is the command of fuel or other source of power; and England's position in the past has been governed largely by her coal fields, which in little more than a century raised her to the forefront as a commercial power. The very abundance of our coal supplies was a source of weakness, as it led to outrageous waste, polluted our atmosphere to a criminal extent, and so encouraged uneconomical methods of using it as seriously to deplete our available stock, the result of which has been the increase in price during the last few years, and the certainty that the future will see further advances but no fall to the old rates. The day of cheap coal has gone, never to return."

⁴ The coal industry in its operations is more comparable to the brickmaking industry than, for example, to the iron industry.



THE OCCURRENCE AND MINING OF BITUMINOUS COAL.
Photograph of a model in the Division of Mineral Technology, United States National Museum

of apprehension for the future.¹ Scattered and unorganized, most of the individual companies are small and financially weak; no adequate cooperation in engineering practice exists; new developments are slow of growth; coal is mined for the most part by obsolescent, long established practice. With no methods of storage developed, the average mine can mine coal only when railroad cars stand ready to receive it; a fluctuating demand, accentuated by seasonal variations, leads to instability of operations; many mines in normal times must close down in slack periods, with destructive effect upon the conditions and supply of labor. For years the price of coal at the mine ranged from \$1 to \$1.15 a ton, a figure so low that only the best and most easily obtainable coal could be extracted by the cheapest methods of mining, irrespective of the waste involved; the tonnage of thin-seam and high-cost areas sacrificed in the process amounts to more than half the total coal produced to date. Many districts have been burdened with a leasing system that obligated the company to remove a given tonnage each year, irrespective of market demand or price, with the result that the richest spots were drawn from seam after seam with irretrievable loss to present needs. Miners' unions in general have fixed wages on the basis of thick and easily worked seams, and imposed such severe penalties upon inferior conditions that the operator is precluded from introducing new and improved methods. Upon all this, the policy of the Government, as exemplified in its anti-trust laws, has forbidden combinations and restrained cooperation, with the result that large-scale, standardized operations, a paramount and distinctive American achievement, is practically lacking in the mining of coal.

These conditions are particularly objectionable because they concern a product of fundamental importance. As compared with the iron industry or the copper industry, the coal industry appears in an unfavorable light in production efficiency. The difference is not to be attributed otherwise than to the competitive system of small-unit mining, which has prevailed for coal in this country and indeed been perpetuated, against a natural tendency otherwise, by a public policy hostile to combination.²

¹ "For several years prior to 1916 it was a matter of general knowledge that the bituminous coal industry in the United States was in an unsound condition. In this basic industry, so necessary to the industrial life of the country, conditions had developed so that it was demoralized financially, wasteful methods of mining resulted in the permanent loss of millions of tons of coal that could have been saved otherwise, the existing mines through lack of demand were kept idle from one-fourth to one-third of the working time, with consequent hardship to labor." Letter from Federal Trade Commission on Anthracite and Bituminous Coal, S. Doc. No. 50, 65th Cong., 1st sess., Washington, 1917, p. 43.

² The individual coal producer can not be held responsible. In any attempt to recover more coal; that is, to make real progress in coal mining, he faced the opposition of the miners' unions, of governmental restrictions, and of probably financial loss. The three formed usually an unsuperable obstacle, although a considerable advance was attained in many creditable instances. If European coal mining conditions were impeded as the industry is in the United States, the industrial activities of Europe would come to a stand-still, if the continent would not actually starve to death.

Coal can not be mined effectively under the present system. The nature of the resource demands integration. Only by the grace of lavish coal wealth has the United States thus far borne the incubus of competition in coal mining. So much is easily recognized, but the means whereby integration may be attained are less apparent. The most practicable path leads toward the enlargement of the public utilities conception to embrace coal.

We may define a public utility as a necessity which does not lend itself to competition. In such a category fall gas, water, and electricity, the telephone service and traction systems of municipalities. In the case of these necessities, public regulation is substituted for the restraining influence of a competition that has been found inexpedient. Coal is a necessity which does not lend itself to competitive mining.

In anthracite is found an interesting spokesman of this principle. The anthracite industry began with many competing units, but the smallness of the field made combination easy and led to the merging of the rival interests in a unified organization. The purpose of the combination, judged by the results, was twofold; to raise the price of anthracite and to increase the efficiency of mining. The disadvantages of the first was commonly recognized, but not the advantages of the second, which were equally significant. Through its monopolistic control of a recognized necessity, the combine years ago became a matter of public concern and the Government faced two alternatives in meeting the problem thereby raised—it could either recognize a combination in restraint of trade, and order its disintegration; or else accept the combination as a procedure essential to the proper handling of the resource, and impose suitable restrictions on the basis that the activity had become automatically a public utility. The first procedure was adopted and the combine was dissolved in so far as its legal existence was concerned; but at bottom the combination persisted, because it was inherent in the nature of anthracite development and could not be legislated out of existence.¹ The alternative chosen by the Government was impossible of execution. It is open knowledge that the anthracite companies to-day operate in concert and fix prices by circular announcements at rates suitable for the effective operation of both high-cost and low-cost mines. As a result, anthracite is mined efficiently in spite of laws opposing the means to that end.

The bituminous industry deals with a necessity that is lending itself less and less to competitive production. Competition is incom-

¹ Writes F. W. Taussig, in a different connection: "The large outstanding fact is the collapse of competitive industry. Combination and monopoly are the inevitable result of the machine processes and large-scale production. Legislation can not prevent monopoly. ... " *Principles of Economics*, New York, 1911, p. 442.

patible with economy, because coals expensive to mine can not compete on a commercial basis with those which may be mined cheaply, and the two, in general, occur in such intimate association that the first, under present conditions, must be sacrificed in order to get the second. If the price is arbitrarily fixed high enough to cover the extraction of high-cost coal, society will pay too much for low-cost coal. If, on the contrary, the price is allowed to seek a natural level, the high-cost coal can not be extracted and much of it becomes permanently lost. It may be asserted that we should use up the cheaply obtainable coal first and then later, when necessary, turn to the coal more expensive to produce. Such would be advisable, were it not for the fact that the fat and the lean occur intimately mixed, and we can not later return and glean the unused values. This limitation is set by the geological occurrence of coal and can not be changed. The only way by which coal can be mined effectively is for the price to be adjusted to the mining costs of each mine, and even to those of different parts of the same mine. Obviously, this would require a pooling of interests—in short, integration.

Bituminous coal, therefore, is a necessity which can not be produced advantageously under competitive operation. It has become by its very nature a public utility, and its administration as such, with integrated activity, is the only practicable way by which its full service can be secured.

Integrated coal mining, under proper limitations, will reduce waste, stabilize production, adjust supply to demand, lessen transportation, and hold the centers of coal production longer than otherwise in their present spots to the advantage of the present distribution of industrial activities, but can not be expected to lower the cost of coal to the consumer. For that purpose, as already pointed out, far-reaching changes in coal utilization alone will suffice. While the price of coal to the consumer has been too high, the price of coal at the mine has been, in general, too low—so low in fact that it has been a small factor in the ultimate cost to the public. That is evident in the contrast between one dollar and the figure the consumer pays. The price of coal at the mine mouth, however, has been slowly advancing; the upward tendency is natural and if left to itself will become stronger and stronger as more and more of the easy-to-get coal is mined. At the present moment the price at the mine is too low, because of the apparent abundance of easy-to-get coal; but within a very few years (if not already), with exhaustion of cheaply mineable coal, the mining costs are bound to attain a rank more consequential in effect upon the ultimate price. It is even now very generally conceded that the "day of cheap coal is over." While integrated mining would add slightly to the average ton-cost of coal at the mine, the effect would

be to relieve the further upward tendency from the acute increase which present conditions will inevitably create. The result, in fine, will be to prolong to the utmost the period of cheap coal.¹

The advantages of integration in coal production are well known in other countries. The thin seams of the eastern coal fields of Canada can only be worked under a cooperative system, as pointed out by the Canadian Department of Mines. Belgian mining law imposes the obligation of cooperative measures upon the coal-mining concessionaire. Cooperative coal marketing has been successfully practiced in many parts of the world, notably in Germany and in the Transvaal.

In short, coal as a resource demands cooperative measures of development. This is true of coal in peculiar degree and holds equally for few other resources. The reason is twofold. In the first place, coal deposits do not lend themselves, as do many other types of mineral deposits, to a graded extraction of values according to the strength of economic demand. In the second place, coal as the major source of power is the basis of modern life, and as such imposes upon organized society a direct responsibility to insure its most effective disposition.

SUMMARY.

Coal is a resource requisite to the functioning of every other resource. The home, industry, and commerce are entirely dependent upon its adequacy. Coal is the basis of organized life. Other raw materials are merely parts of the social fabric—incidental to it; iron, for example, does not come to the consumer as such, but coal is comfort and energy as well as a commodity to be manufactured. Coal, therefore, in its far-reaching consequences, has assumed a responsibility equalled by no other substance.

Under present conditions, coal fails to measure up to that responsibility. It is wastefully mined, wastefully distributed, and wastefully utilized. It is wastefully mined because of the conditions of competition which society imposes upon its exploitation. It is wastefully distributed as a result of the unnecessary transportation in regions supplied with water power or with coals less desirable than those consumed. It is wastefully used due to the lack of by-product recovery as an accepted economic practice.

The wastes in mining may be decreased through integrated operations, which will obviate the economic necessity for waste. Coal submits itself to integration as a public utility.

The wastes in distribution may be reduced through the development of hydroelectricity and the coal-field generation of carbo-

¹ It need scarcely be pointed out the advantages of by-product utilization may be realized without the gains of integrated mining, but the first may be largely nullified through the neglect of the second.

electric power, thus relieving coal of unnecessary duties, and by improvements in utilization, thus destroying the over-dependence upon high-grade coals which now necessitates undue haulage.

The wastes in utilization may be done away with by establishing a method of separating the energy-producing constituents of coal from the commodity values and using the products to their common advantage. The most logical point of attack is the municipality, to which may be attached a public utility plant converting raw coal into smokeless fuel—artificial anthracite plus gas, or gas alone—and valuable by-products, ammonia, benzol, and tar. Such a plant would supply the fuel needs of the community and ship the surplus by-products to serve as raw material for a coal-products industry, developed thereby to proportions consistent with its importance to social progress.

Integrated mining will lessen the increased costs that will come with the impending extraction of thick-seam and easily obtainable coals.

Reduced coal transportation will remove an unnecessary burden from the railways and prevent the repetition of the congestion difficulties so acutely felt during the winter of 1917-18.

By-product utilization will give cheaper fuel through the advantageous disposition of all the values contained. It will also end the smoke nuisance, relieve transportation, and cause the growth of a great coal-products industry with ultimate possibilities ranging beyond the grasp of the imagination.

This paper does not presume to set forth the exact methods whereby these results may be attained; the procedures remain to be worked out in detail. Its purpose, however, has been to present a line of attack, drawn up on the basis of the character and extent of the resource, which may be followed to specific advantage. There are no serious technical obstacles in the way; the chief requisite for progress is a popular appreciation of the fact that coal contains greater values than society is getting from it. From this realization will spring a public demand that scientific and technical knowledge be used, not merely in making improvements in the details of present practice but in revising that practice itself and shaping a policy of administration more in keeping with what is known to be the potentiality of coal. "Mankind," writes John Dewey, "so far has been ruled by things and by words, not by thought * * *. If ever we are to be governed by intelligence, not by things and words, science must have something to say about *what* we do and not merely *how* we may do it more easily and economically."¹

¹ It should be borne in mind that fundamental changes in coal economics are capable of just as much harm if handled ill-advisedly as of good if competently directed. Unless a type of public management superior to anything this country has developed in the past can be put forth, the whole matter might better be left in its present state of inadequacy.

And, in conclusion, it may be asked what are the assets and the liabilities in this business of demanding a full accountability from coal. Here is the balance sheet:

Assets:

Ample coal resources.
By-product coke experience.
Municipal gas-plant installations.

Liabilities:

Tradition.
Character of the past administration
of the average public utility.
Character of our past conduct of technical matters.

The assets are large, but the liabilities, it must be admitted, have been insistent enough to block progress in the past. Whether they will continue to overbalance the assets will depend upon the course of public opinion. It is up to the man in the streets to determine which shall prevail. A continuation of the present system of coal economics may be justified on the basis of indifference to progress, but not on the basis of ignorance; its unnecessary prolongation should afford a prospect intolerable to the thinking man.



VIEW OF THE OCCURRENCE AND MINING OF OIL AND GAS.

Photograph of a model in the Division of Mineral Technology, United States National Museum.

PART II.

PETROLEUM.¹

INTRODUCTION.

Petroleum is of peculiar value to society because it is the sole source of gasoline, the dominant motor fuel; provides kerosene, the most important illuminant outside of cities; and yields lubricating oil, upon which the wheels of industry revolve. In addition, it has come to be an essential fuel in the Southwest and on the Pacific coast, where coal is lacking;² is requisite to the operations of an oil-burning navy; and forms the starting point for an oil by-products industry, a branch of chemical manufacture still in its infancy and offering unlimited possibilities of development.

The liquidity of the crude product makes petroleum unique among mineral raw materials, contributing wide commercial availability through the ease with which the substance may be mined and handled; while the magnitude of the resource has given confidence for the extensive mechanical developments essential to its use. Hence the employment of petroleum is deeply rooted among the practices and needs of modern life, and any tendency toward disuse of its essential products,³ either through undue increase in price or from decline in production, will mark a turning point in material comfort and industrial advantage, the deferring of which becomes an object of universal concern. As the petroleum deposits of the United States have been drawn upon with extraordinary rapidity and the supplies have already suffered serious depletion, the matter of their approaching exhaustion assumes the light of immediate importance. The comforting assertion that such considerations may be safely left to future generations does not apply to petroleum.⁴

¹ An economic study of a limited resource.

² Part of the industrial activity of the eastern part of the country is now dependent upon fuel oil.

³ See p. 93 for qualifications in respect to fuel oil.

⁴ " * * * petroleum is a priceless resource, for it can never be replaced. Trees can be grown again upon the soil from which they have been taken. But how can petroleum be produced? It has taken the ages for nature to distill it in her subterranean laboratory. We do not even know her process. We may find a substitute for it, but have not yet. It is practically the one lubricant of the world to-day. Not a railroad wheel turns without its way being smoothed by it. We can make light and heat by hydroelectric power, but the great turbines move on bearings that are smothered in petroleum. From it we get the quick-exploding gas which is to the motor and the airship what air is to the human body. To industry, agriculture, commerce, and the pleasures of life petroleum is now essential." (Franklin K. Lane in Reports of the Department of the Interior for 1915, Washington, vol. 1, p. 16.)

THE RESOURCE.

NATURE.

Petroleum, or crude petroleum as the raw or unrefined product is often termed, is an oily liquid varying considerably in appearance according to the locality from which it comes. It is an extremely complex mixture of organic compounds, chiefly hydrocarbons,¹ but substances containing sulphur, oxygen, and nitrogen are also present in small amounts. It contains, therefore, five chemical elements of the first importance in life processes, a circumstance that suggests at once an organic origin and determines the important rôle that this substance is due to play in filling the needs of man.²

If crude petroleum is exposed to the air, it gradually thickens until a solid residue is left. The first product given off is natural gas; then liquid components evaporate in the order of their lightness; and the final residue is composed largely of either paraffin wax or asphalt. Petroleum is thus seen to be a mixture of different liquids dissolved in one another and holding in solution also natural gas and solid substances. This conception correlates natural gas as a by-product of petroleum³ and affords a simple epitome of the changes more rapidly induced when petroleum is subjected to refining.⁴ The asphalt lake of Trinidad and the ozokerite deposits of Galicia and Utah represent natural residues from the prolonged evaporation or natural distillation of petroleum.

While petroleums vary considerably in character, they fall chiefly into two classes according to whether the residue yielded is predominantly paraffin wax or asphalt.⁵ This broad distinction is of great economic significance, because the paraffin petroleums, occurring chiefly in the eastern part of the country, came first into use and therefore determined the current refining practice and the existing demand for petroleum products; while the asphaltic petroleums, exploited later in the Gulf region and California, found their immediate commercial outlet in the form of fuel. The higher gasoline content of paraffin oils, coupled with the distance of coal from the Californian region,⁶ gave free scope to the economic differentiation of the two types.

¹ Compounds composed of hydrogen and carbon. These substances are present by the hundreds.

² It would be shortsighted to assume that petroleum even now has displayed its full measure of versatility.

³ Part of the natural gas production of the country, indeed, comes from petroleum wells.

⁴ The processes of refining, of course, involve some chemical changes also.

⁵ The first are said to have a *paraffin base*; the second, an *asphaltic base*, or called merely asphaltic petroleums. There are also intermediate oils with almost equal proportions of paraffin and asphalt.

⁶ The presence of coal fields in California, however, would have scarcely deterred the development of the oil fields of that State, although their presence would afford a pleasing contemplation now.

OCCURRENCE.

Because of its liquidity, petroleum differs markedly in geological occurrence from all other minerals. It appears on the surface in some localities in the form of oil seeps, but commercial quantities of petroleum are found only at depth inclosed within the rocks of the earth's crust. Its occurrence is very similar to that of artesian water, with which, indeed, it is frequently associated. It saturates certain areas of porous rocks, such as beds of sand or sandstone, tending to accumulate where such strata occur beneath denser, impervious layers. Occurring in this way under the pressure that obtains at depth, carrying immense quantities of natural gas in solution, and almost invariably associated with water, petroleum is capable of movement and in general migrates upward until it encounters a layer of impervious rock so disposed in structure as to impede further progress and impound the oil into a "reservoir" or "pool"¹ (see pl. 5 and fig. 13).

The geology of petroleum, therefore, is the geology of rock structures, and the skilful mapping of the surface disposition of rock formations gives the means for determining the structure at depth and hence the position of structural features favorable to the accumulation of oil. When this information is supplemented by careful records of the rock layers encountered as wells are drilled, a three-dimensional knowledge of the earth's crust is obtained, remarkable for its detail and accuracy. Thus, by the aid of geological methods, the development of petroleum fields may be changed from a gambling venture to an exact science, and, if the scale of operations be sufficiently large, it may be figured rather closely how much oil can be obtained from a given expenditure of money.² Instead of representing the most uncertain venture in the world, therefore, oil production can now be made as definitely an engineering project as the mining of a clay bank.

The migratory character of petroleum, coupled with the general tendency of stratified rocks to occur in broadly undulating folds and shallow domes, gives peculiar significance to the underground disposition of the oil deposit. Thus the process of winning the oil consists in puncturing the structural feature that holds it in restraint so as to give free scope to a movement upward to the surface. Accordingly the position of the oil grows highly unstable as soon as the deposit comes under exploitation and this variability affects the entire geo-

¹ These words are misleading in that they suggest great open spaces filled with oil rather than areas of oil-saturated rock. Water is sometimes lacking, and then the oil migrates in a different manner.

² Another interesting application of geology to oil exploration has been developed by the Standard Oil Co. of California and by the United States Geological Survey. It has been found that the chemical composition of the water encountered by the drill will give some indication of the proximity to oil and hence serve as a guide to a successful development. (See G. S. Rogers, Chemical relations of the oil-field waters in San Joaquin Valley, Cal., Bull. 653, U. S. Geological Survey, 1917.)

logical unit or pool. In consequence the joint ownership or joint exploitation of a single pool results in the inability to apportion the product on any arbitrary basis of vertical boundary planes,¹ and the oil, therefore, is practically no man's property until it is got above ground. This circumstance is almost invariable and the customary method of exploiting the single oil pool by a series of small, independent holdings has cost an inordinate toll of waste and loss.² The economics of oil production is out of adjustment with the geological occurrence of oil and the latter, being a physical fact, can not be altered.

ORIGIN.

Few questions in geologic theory have met with more discussion than the origin of petroleum. It is reasonably certain, however, that petroleum in the main is of organic origin and represents the natural distillation products of plants and animals buried in the muds and oozes of ancient swamps and seas. Vast rock formations, indeed, are known which are nothing more than the accumulated débris of innumerable organisms, compressed, hardened, and changed into rock. Fossiliferous limestones, phosphate rock, and coal seams are familiar examples which underlie thousands of square miles of the earth's surface. It would be strange, in fact, if in the process of formation oils were not produced, when organic products to-day, subjected to heat and pressure, yield oily substances not unlike petroleum. Sediments carrying organic remains are sufficiently abundant and widespread to account for all the petroleum that the oil fields of the world give promise of producing.

DISTRIBUTION.

While petroleum is of very common occurrence in traces, areas underlain by commercial quantities are somewhat restricted and fields of great importance are few. Thus in spite of an intensive search for new oil regions and vigorous campaigns of development carried on in all parts of the world, the entire supply comes largely from three countries, as shown in the accompanying chart (fig. 2).

In the United States, the output is derived from a number of widely scattered regions known as "fields," whose distribution is shown on the map (fig. 3), and whose importance is indicated by the charts (figs. 8 and 9.) In a broad way, these fields fall into two groups—those of the eastern half of the United States, bound into a single unit by an extensive system of pipe lines, and those of California, connected with the rest of the country by railroad transporta-

¹ It is a rather curious commentary on the obsolescence of American mining law that vertical boundaries are applied to oil deposits where they have no meaning, but are not applied in the case of outcropping ore deposits, where they are both appropriate and desirable.

² See figure 12.

tion only.¹ The intermediate fields of Wyoming² do not come within this rough geographic classification, but with further development they will presumably be joined by pipe lines³ with the group of the eastern half of the country. It will be observed that the Kansas-Oklahoma field of the eastern group and the California field are about equal in production and dominate the petroleum output of this country, together contributing over two-thirds of the total supply. (See fig. 8.)

The development of petroleum production in the United States from 1880 to 1917 is indicated graphically by the chart (fig. 4). From the situation there depicted, two features of particular significance stand out—the slow increase in domestic production up to 1900, less marked than the increase in the corresponding foreign production, and the rapid domestic growth between 1900 and 1917, con-

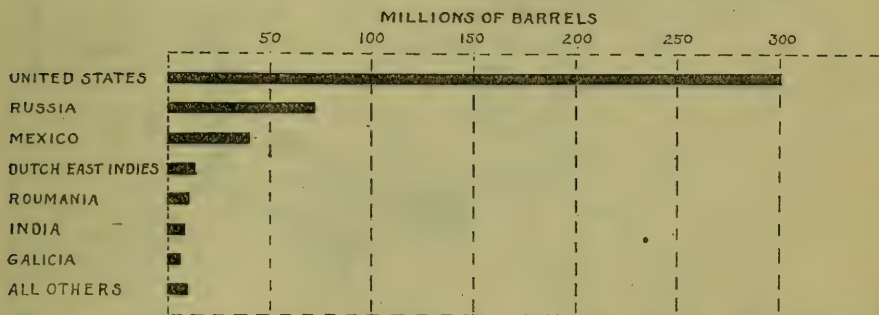


FIG. 2.—WORLD'S PRODUCTION OF PETROLEUM IN 1916. DATA FROM U. S. GEOLOGICAL SURVEY.

trasted with a nearly constant production for foreign countries during that period. This emphasizes the fact that since the beginning of the twentieth century, the rapidly increasing use of petroleum throughout the world has been met largely through the intensive exploitation of American deposits. Thus the United States has assumed a dominant position in respect to this commodity, producing now two-thirds of the world's supply.

THE INDUSTRY.

The activities concerned with the production, transportation, refining, and distribution of petroleum constitute the petroleum industry. In quantity, value, and importance of production, this industrial field stands among the foremost in the country. It is notable, especially, for the scope of its operations, which embrace diverse activities usually the functions of separate industries—a characteris-

¹ Also by water transportation through the Panama Canal.

² Including Colorado.

³ Probably by way of the shale-oil region of Colorado. (See map, fig. 3.)

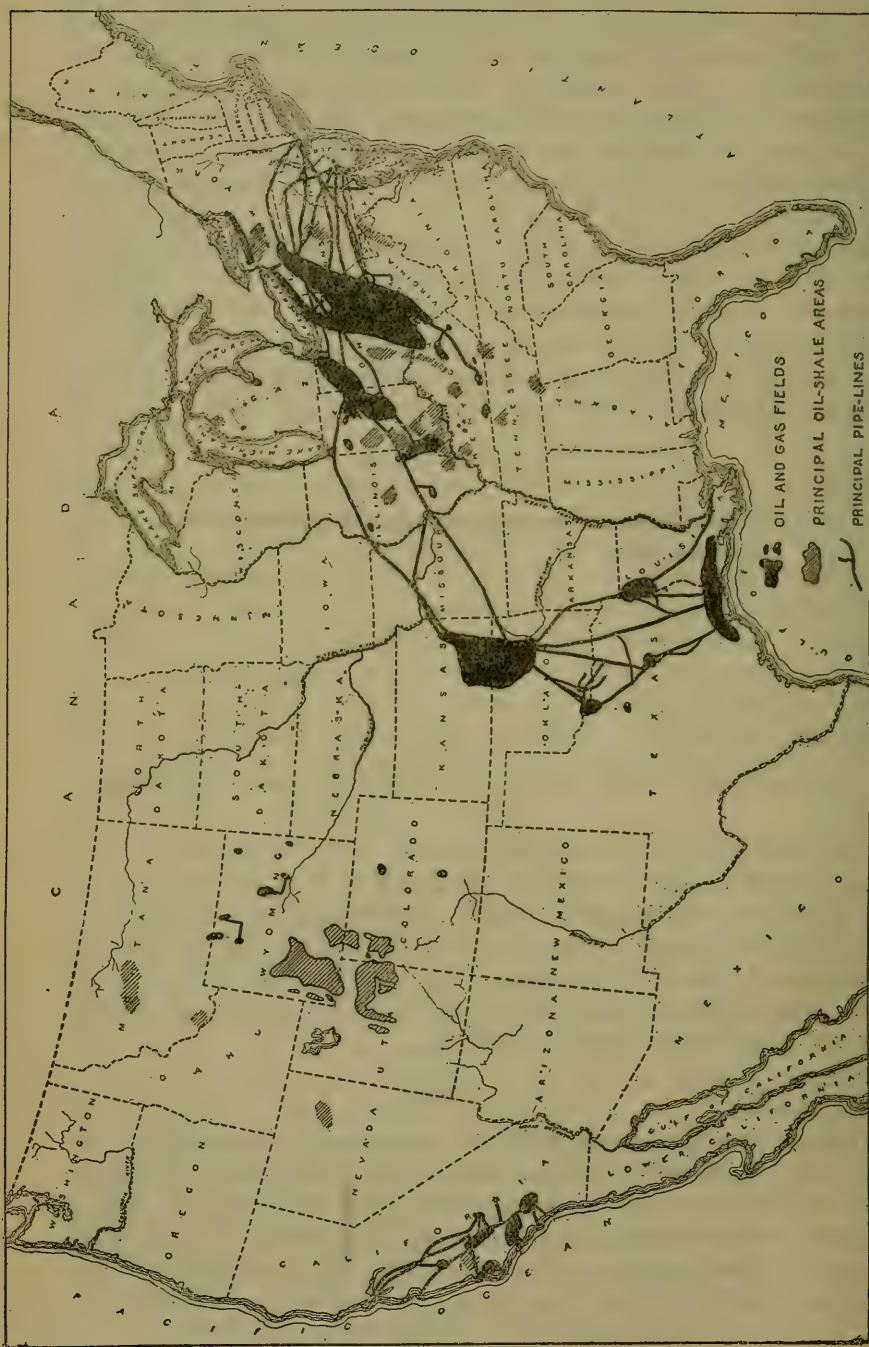


FIG. 3.—SKETCH MAP SHOWING THE DISTRIBUTION OF THE OIL AND GAS RESOURCES, TOGETHER WITH PRINCIPAL PIPE LINES OF THE UNITED STATES. GENERALIZED FROM DETAILED MAP BY JOHN D. NORTROP, OIL AND GAS FIELDS IN 1916, CORRECTED TO MARCH, 1917, U. S. GEOLOGICAL SURVEY. OIL-SHALE DATA FROM U. S. GEOLOGICAL SURVEY AND OTHER SOURCES.

tic arising from the peculiar nature of petroleum. In most other industries, to cite the most striking distinction, transportation over alien lines separates the producing activity from the manufacturing activity, creating a break between continuity of operations; in the case of petroleum, however, the liquidity of the crude product adapts it to specialized transportation through pipe lines, themselves a part of the resource development. In consequence, the petroleum industry in its ideal form represents a type of industrial activity more highly coordinated than other industries of the present day, affording, therefore, an important object lesson for constructive consideration.

The petroleum industry, in point of fact, however, is not coordinated throughout, but at present breaks into two portions, by no means in complete adjustment—the production of petroleum and the handling of petroleum with its threefold aspect of transportation, refining, and distribution. The conditions of producing crude petroleum are wholly different from those involved in its treatment after it is above ground. This is reflected in the circumstance that over 15,000 individual companies are engaged in the mining of petroleum, while the organizations concerned with the handling of the product are numbered by a few hundred. A large part of the crude production,¹ therefore, appears above ground through the efforts of a great many small operators, while the bulk of the transportation, refining, and distribution is taken care of by a very few large organizations.

PRODUCTION.

Petroleum is won in commercial quantities through wells drilled to varying depths into the crust of the earth. The drilling is commonly done by means of a heavy string of tools suspended at the end of a cable and given a churning motion by a walking beam rocked by a steam engine. This method is known as the standard or percussion system of drilling. The steel tools, falling under their own weight, pulverize the solid rock encountered and literally punch their way to the depth desired. To prevent the caving in of the hole, but especially to avoid the inflow of water from water-bearing formations, the well is lined or “cased” wholly or in part with iron piping, which is inserted in screw-joint sections at intervals during the drilling and forced down to positions needful of such protection. The well does not taper, but if deep changes to successively smaller bores at several points, resembling in section a great telescope.²

¹ Estimated roughly at four-fifths.

² The drilling of an oil well is graphically described by George Fitch in the following paragraph:

“An oil well is a hole in the ground about a quarter of a mile deep, into which a man may put a small fortune or out of which he may take a big one. And he never knows

Another method of drilling known as the rotary system is also in common use, being particularly adapted to regions where the sides of the well tend to cave badly, as in California and some other localities. This system requires more elaborate machinery than the standard, as the drilling and insertion of the casing is simultaneous. The iron casing, indeed, is tipped with a steel bit and rotated so as to bore its way downward like a great auger.

The oil well is marked by a tall wooden framework called a derrick, which permits the string of tools and the casing to be inserted or withdrawn when necessary. It is the presence of derricks that gives the characteristic appearance to an oil field landscape. Oil wells vary from a few hundred feet or less in depth, requiring a few weeks only to drill, to those thousands of feet deep and demanding months of continuous labor before production starts.¹ The cost of drilling normally runs from \$1 up to \$15 and more a foot,² while the rate of progress, except for shallow wells, ranges from about 60 down to 10 feet a day, slowing, of course, with depth. It is apparent, then, that oil-well drilling is a slow and costly process and makes a heavy draft upon the iron and steel industry, consuming indeed about one-twelfth of its output in ordinary times.

A well favorably located eventually penetrates an oil-bearing bed, and the petroleum may spurt forth in a lavish stream under the influence of the natural gas held in solution under pressure.³ Such wells are called gushers and some pour forth prodigious quantities of oil.⁴ Other wells flow with less violence, and many, lacking in

until the hole is finished * * *. It takes a couple of thousand dollars, several months, and a couple of noncommittal men in mud-plastered overalls to dig an oil well. They begin by going up about 60 feet. When they have finished their derrick, they hang a drill on it weighing half a ton. Then the men hitch the drill to an engine and punch a 42-centimeter hole in the earth's crust. Sometimes, after they have been punching away for several weeks, the hole blows the derrick into the sky, utterly ruining it. Then the owner shrieks with glee and employs 500 men to catch the spouting oil in barrels. But sometimes the derrick is as good as new when the hole is finished. Then the owner curses and takes the derrick away to some other place which smells oily."

¹ The deepest wells are slightly over 7,000 feet, but such depths are exceptional. The deepest well in the world is near Clarksburg, W. Va., having recently reached a depth of 7,363 feet, according to the U. S. Geological Survey.

² This is the cost in normal times. At present, the cost is more than twice the usual figure. Thus to drill a well 3,000 feet deep might now cost from \$50,000 to \$80,000.

³ The action is analogous to the rush of soda water from a bottle when the cork is removed.

⁴ "On the Fourth of July, 1908, the greatest oil well of the world was struck at San Geronimo, on the Gulf of Mexico, 67 miles north of Tampico. When struck, the oil gushed so rapidly that before the fire in the boiler of the engine running the drilling machinery could be extinguished the flowing oil reached it and burst into a mass of flame which for two months burned 60,000 to 75,000 barrels of oil per day with a flame from 800 to 1,400 feet in height, and 40 to 75 feet in width, making light enough to be seen by ships 100 miles at sea, and to permit a newspaper to be read 17 miles away. After the loss of \$3,000,000 the fire was put out, but the oil flowed so rapidly that it could not be carried away or put in tanks, and the English owners saved their oil only by confining it in a reservoir one-fourth of a mile long made by heaping up earth embankments to keep the oil from flowing away like water. Even this well was later surpassed by the Potrero del Llano No. 4 well near Tuxpam, Mexico, which yielded 160,000 barrels a day for some time."—J. Russell Smith, *Industrial and Commercial Geography*, 1913, p. 409.

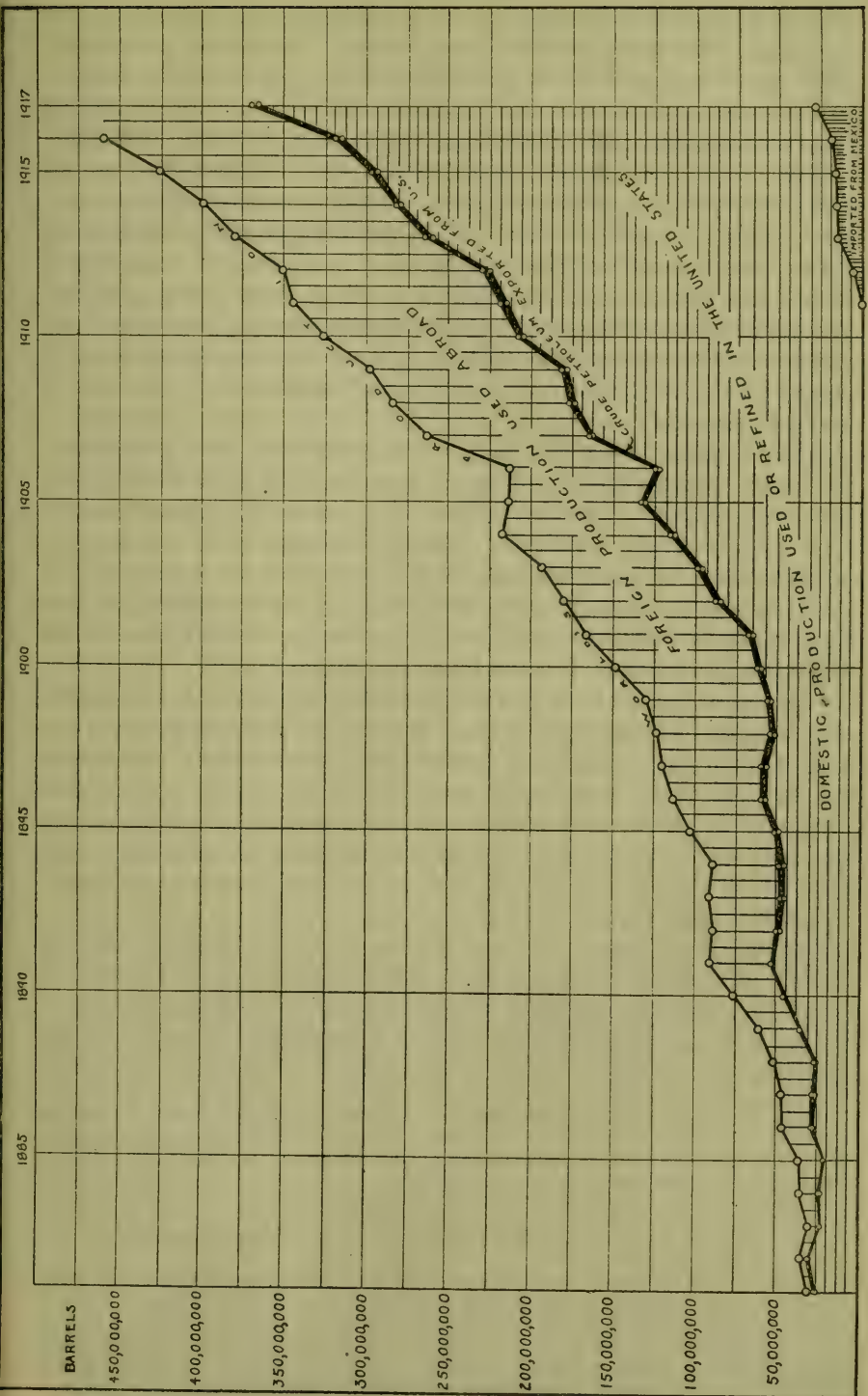


FIG. 4.—CHART SHOWING PETROLEUM USED IN THE UNITED STATES AND THE REST OF THE WORLD FROM 1880 TO 1917. DATA FROM U. S. GEOLOGICAL SURVEY.

notable quantities of natural gas, yield only under the inducement of pumping. All wells, however, soon reach a maximum production, after which they pass into a period of decline, and eventually become extinct.¹ So inexorable is this procedure that a curve may be plotted in advance depicting the future behavior of a given group of wells.

When an oil well becomes extinct, its nonproductiveness does not signify that all the oil is exhausted. On the contrary, current practice in general leaves over half of the oil underground still clinging to the pores and capillary spaces in the rock. To obtain a greater yield from productive ground constitutes a problem of the first magnitude, and promising results have been obtained by forcing compressed air into some of the exhausted wells of a group, with the result that the laggard oil is swept to the neighborhood of other wells from which it may be pumped.²

When a gusher is struck, adequate facilities are often lacking for catching and storing the product, so that veritable lakes of oil gather between quickly thrown-up earthen embankments. Quantities, in such instances, are dissipated through seepage and evaporation, while disastrous fires of spectacular nature are not uncommon. With more careful development, however, field storage tanks shaped like huge cheese boxes are in readiness to receive the oil and prevent the glaring waste inherent in more hasty operations.³

Turning attention from the single well to the oil field, we observe that in petroleum mining sustained production depends upon an unbroken campaign of drilling operations. Thus the producers must not only draw oil from existing wells, but at the same time must persist in the drilling of an *increasing*⁴ number of new wells and in the location of promising territory in advance of drilling. Any factor that retards any one of these three related activities quickly reacts to cause a falling off in production.⁵

Output, development, and exploration, therefore, must go hand in hand. In a general way, this threefold activity of production is carried on either as a large-scale engineering procedure or as a composite of small, individual operations. Large oil companies engaged in production naturally adopt what might be called the engineering

¹ Wells during decadence are spurred into temporary renewals of activity by the explosion of charges of nitroglycerine at their bottoms. The life of an oil well varies from a few months to twenty years or more. The average life of Pennsylvania wells is estimated to be seven years.

² See J. O. Lewis, Methods for increasing the recovery from oil sands: Bulletin 148, U. S. Bureau of Mines, 1917.

³ Only the most carefully constructed tanks prevent the escape of the volatile constituents of petroleum.

⁴ As an oil field ages, new wells yield less than the initial yields of the earlier wells, hence a growing number of active wells is necessary to maintain production.

⁵ For example there has recently been a strike in one of the Gulf fields, of such a nature as to affect not the current production, but the drilling campaign upon which the production of coming months is dependent. Thus a wave is started which will not be felt until the future; and like all waves, once started, nothing can stop the reaction.

procedure, while small companies and individual operators tend more to follow what is picturesquely termed "wildcat"¹ operations. Thus the production of oil is in part dependent upon stable conditions, but in larger part is still a type of activity which approaches in considerable measure a gambling venture. This is why oil mining is generally looked upon and commonly described as hazardous from a financial standpoint. The hazard is inherent only in small-scale operations.

The engineering type of production makes use of skilled geological knowledge in its campaign of oil production. The modern oil company employs a large geologic staff, which determines by detailed field surveys the most promising spots for drilling.² The growth of oil geology has been rapid and while, of course, geologic science can not strike oil with every drill, it does multiply by many times the chances of each drilling operation. It has been stated that "the operator who plays geology has a fifty times better chance of striking oil than he who does not."³

But in spite of numerous highly organized production activities, the fact remains that the petroleum production of the United States is in considerable measure dependent upon a hit-or-miss plan of exploitation. Were it not for the wildcatter, who stakes his all (sometimes borrowed) on the chance that a random hole drilled in the general vicinity of productive territory will yield the hoped-for return, the output of petroleum in a country which produces two-thirds of the world's supply would fall to an utterly inadequate figure. The gambling instinct is still the prime motive power that lifts most of the oil produced in this country. Familiar is the expression, once an oil man, always an oil man.⁴

¹ In strict oil-field parlance, to *wildcat* is to drill a well where oil has not been proven to exist, as opposed to drilling a well in the midst of producing wells. Thus both large companies and small may alike engage in *wildcatting*, although, as a matter of course, most of the *wildcatting* is done by small operating units.

A good picture of wildcat operations is given by W. S. Tower in *The Story of Oil*, 1909, p. 66: "To call a well a wildcat venture means merely that the drilling is done on untested territory, or on land not definitely known to be oil producing. The wildcat operation is, therefore, an out-and-out gambling process by a man who is willing to stake a few thousand dollars against heavy odds that he will find oil at some depths in a drill hole a few inches in diameter. If luck favors him, his winnings may be enormous; if he loses, his only hope is to pull up, leave the hole where his money is sunk, and move to some other place."

² The implication, of course, is not intended that small companies do not employ geologic service, but, in general, the smaller the company the less likely it is to be capable of making the necessary expenditure. The Federal Government, through the U. S. Geological Survey, has rendered a signal service to the small operator through its published reports and maps covering oil regions, but the small operator has not in all instances taken advantage of even published geological information.

³ Dorsey Hager, *Bulletin American Institute of Mining Engineers*, October, 1917, pp. 1793-5.

⁴ An unfortunate and far-reaching consequence of the present method of production is the extension of the gambling aspect into widespread public consciousness, leading to a susceptibility to the purchase of stock in illegitimate oil-mining ventures. The losses involved in the readiness of the public to embrace the schemes of fraudulent oil promoters are untold and have reacted unfavorably upon public opinion in respect to the legitimate industry.

It is not intended, of course, to throw oil production into an unfavorable light by thus focussing attention upon its gambling aspect; to exert onerous effort (such as oil field development demands) under the incentive of rich possibilities of reward is a straightforward and legitimate business activity. It is frequently questioned whether oil development could be sustained without prospect of large pecuniary gain.¹ The point is merely made that under present circumstances petroleum production is dependent upon this psychological aspect, acutely developed, which is both subtle and intangible, yet profoundly important in conditioning the output; this factor must be reckoned with in contemplating the course of the resource development.²

¹ It is interesting to note an English view of this aspect of production: "The large producers and refiners, appreciating the value of the speculative oil seeker, foster rather than discourage his activities. He absolves them from considerable preliminary expense in drilling and proving a new territory. Their work is reduced to purchasing and transporting the raw material when it has been tapped. It is a development which is peculiar to the United States. In other oil-producing countries such a tendency is not supported." (Frederick A. Talbot, *The Oil Conquest of the World*, London, 1914, p. 58.)

² The distinctive "color" of oil production can perhaps be effectively conveyed by means of a number of quotations:

"The great army of men who produce our oil for us are in many cases of the rough-and-ready sort, but they are not penny-splitters and they are not hold-up men. Few of them have diplomas to exhibit, and their English may not be of the best; but they know how to do things with their hands, feet, and heads—and I do not believe that there is a more loyal or a more likable bunch of men in the world." H. L. Doherty.

"* * * the producing branch of the industry * * * is a picturesque blending of temperament, personality, and psychology with all the mingled burlesque and common sense that one would expect from unorganized energy and enthusiasm. Production is largely the outgrowth of the sporadic efforts of many 'wildcatters' of many moods and varying capabilities." H. L. Wood in *Sinclair's Magazine*, October, 1917, p. 31.

"It is the speculative character of the work that appeals to the American. He is a born gambler, delights in juggling with fortune; with him speculation is second nature. In the quest for oil he has unlimited capacity to gratify his desires to become rich quickly." This last is by an English writer, Frederick A. Talbot, *The Oil Conquest of the World*, London, 1914.

"Let us consider for a moment the vital question of drilling experimental wells—'wildcatting'—standing at the base of the discovery of new oil fields, without which the industry would dry up. For every field discovered there are hundreds—perhaps thousands—of experimental, worthless holes drilled—'wildcat' wells. The 'wildcatter' is moved to take his long hazard, his big chance, his desperate gamble, through the highly speculative considerations surrounding his work—the hope of a great reward; realizing, however, all the time that the chances are ten to one against his success * * * clearly, the practical course is to leave to the thousands of men who are willing when left free of interference and free to act upon their own volition, the opportunity and the privilege of making the venture—taking the chance. Most of them will lose. The few who gain will deserve their reward. The sum total of their efforts will be for the world at large. * * * As a rule, large companies or corporations have not been the discoverers of new pools or fields, except in very rare instances. They are generally found by individuals or small groups of tenderfeet at the game * * *." Instances taken at random from an article, "The future of the oil industry," purporting to represent the views of the "leading men of the industry," as ascertained by a questionnaire, published in the *Semiannual Oil Industry Review*, The Evening Post, New York, Mar. 2, 1918.

"* * * The optimistic wildcatter, that virile pioneer of the oil field who cheerfully takes the gambler's chance in the hope of reaping a reward commensurate with the risk." M. L. Requa, *War Service of the Petroleum Industry*, Olddom, April, 1918, p. 214.

Production and consumption, of course, can not coincide in amount; hence, of necessity, there are reserves of petroleum above ground which serve as an expansion and contraction joint, so to speak, between supply and demand. When there is an overproduction in respect to current needs, the reserves or, as commonly termed, the stocks increase; conversely, with industrial expansion or lessened output, drafts are made upon the stocks, which then decrease. The condition of the stocks, therefore, is a sort of pulse to the crude-oil market, since prices, under the influence of the same factor of supply and demand, fluctuate in like manner. The stocks, under conditions of unorganized production, have come to be unusually great during the past few years, representing roughly in 1916 a six-months' supply.¹ At the present time, under war conditions, the stocks are being rapidly depleted to meet a consumptive demand which is greater than the productive capacity of the country.

The price of crude petroleum at the well varies considerably according to quality, distance from market, and other factors. The paraffin oils of light gravity, such as those produced in Pennsylvania, are the most valuable because they yield the largest percentage of products in demand, while the asphaltic oils of heavy gravity, such as those of California and part of the Gulf region, command a price roughly a fourth of that which the best quality oil enjoys. Thus the Pennsylvania crude commenced 1915 with a price of about \$1.50 a barrel and ended 1917 at about \$3.75, while during the same period California crude² climbed from about 35 cents to practically \$1. These two types of oil represent the extremes of quality, with the factor of distance from markets nearly the same in the two instances. Between these limits range the prices of all the other oils of the country, the quotation at any given time and location being a complex of quality and of balance between supply and demand, with all the qualifications that the latter expression involves. The wide range in prices for a single raw material, with the utmost concession to differences in location and composition, suggests an undue discrepancy to be credited against the conditions under which oil is produced.

The dependence of sustained production upon an unbroken campaign of drilling exploration, and the extent to which such a campaign is carried on by "wildcat" operations on the part of small companies and individuals, lead to many perplexing legal and economic difficulties. Land, of course, is rarely owned by the operator, so that he must ordinarily either purchase or lease the oil (and gas) right. The laws connected with oil lands have not been modernized, but are confusing and in part conflicting, so that the operator is put

¹ The stocks have been estimated as follows: On hand Jan. 1, 1916, 186,000,000 barrels; on hand Jan. 1, 1917, 174,000,000 barrels; on hand Jan. 1, 1918, 153,000,000 barrels.

² That below 18° Baumé in gravity.

to undue trouble and expense in meeting the legal requirements of his holdings. Moreover, the method of leasing under small-unit operations leads to a wasteful competition between neighboring wells in their race to secure a maximum production within the period of the lease—haste, with waste, being an economic necessity in such instances. In regard to lands owned by the Government, the legal regulations are so ill-adapted to progress that R. H. Johnson and L. G. Huntley in their "Principles of Oil and Gas Production,"¹ remark: "Most of the public lands which seem promising for oil and gas have been withdrawn,² since there is universal agreement by both Government and producers that the present law, by which oil and gas lands are taken as placer claims, is utterly unadapted to the industry.³ The development of the lands which are not withdrawn would best be postponed until a new oil and gas prospecting permit and leasing law is passed, and the oil placer claim law revoked, except where work is already started."⁴

TRANSPORTATION.

One of the remarkable and impressive features of the petroleum industry is the fact that the crude product is transported through a system of pipe-lines that connect the points of production with refineries, markets, and seaports. This method of handling is natural and inevitable with a liquid product consumed in bulk, as evidenced by a somewhat analogous method of transportation adopted for municipal water supply. While petroleum shares with coal the main responsibility for energizing the mechanical activities of the country, it is interesting to note that crude oil, unlike raw coal, imposes normally no appreciable burden upon the railroads.

¹ New York, 1916, pp. 112-113.

² That is, closed to private development pending a determination of policy. The Secretary of the Interior, in a letter to the chairman of the Committee on the Public Lands, House of Representatives, under date of Apr. 24, 1917, writes: "Six million four hundred and ninety-one thousand one hundred and forty-five acres of public lands believed to contain oil are withdrawn from development. A part of this area is proven territory, in direct touch with pipe lines and refineries, and the product could be made immediately available by the enactment of this measure. I therefore earnestly recommend that H. R. 3232 be enacted at the earliest practicable moment as a war measure." (Committee Print of Departmental Reports on H. R. 3232 and S. 2812, Washington, 1918, p. 4.) The matter is still (July 1, 1918) under abeyance.

³ See letter of the Secretary of the Interior to chairman of the Committee on Public Lands, under date of Jan. 3, 1916 (published in Committee Print of Departmental Reports on H. R. 3232 and S. 2812, Washington, 1918, p. 8), which states: "Oil and gas lands or deposits are now subject to location and entry under the placer mining laws. These laws have generally been unsatisfactory, both from the standpoint of the prospectors and operators and of the Government. There is nothing in the present law to protect the prospector during the preliminary period, when, through the expenditure of large capital, he is engaged in drilling, and the limitations as to acreage contained in the existing laws are also a temptation to evade, through the use of dummy locations."

⁴ It is unfortunately true that mining in the United States has been badly impeded by a set of laws handed down from the past and wholly unadapted to modern conditions of mining. Sporadic attempts, usually unsuccessful, have been made to improve certain details of these laws, but in general American mining law remains a discredit to the Nation. In the present war emergency the country is paying a heavy penalty for its neglect of this matter.

The pipe-lines of the United States, comprising those of the subsidiary companies of the Standard Oil and a number of independent companies, aggregate thousands of miles in length and form a network spread over much of the country.¹ They consist of trunk lines, the longest of which connects Oklahoma with the Atlantic seaboard by way of Illinois, and gathering lines leading into the main channels. The whole system is comparable to the arteries and veins of the human body.

The pipes vary in diameter from 2 to 12 inches, but 6 to 10 inches represent the common sizes. The piping is made of iron plate and is ordinarily placed below the surface of the ground. At intervals of from 15 to 30 miles, according to the viscosity of the oil, are pumping stations, where powerful pumps seize the spent oil and force it forward with renewed vigor. In the case of heavy, viscous oils, such as those of California, it becomes necessary to heat the product at each pumping station to facilitate its progress. Unlike a railroad, the pipe-lines, in general, follow a direct course, uphill and down.² The pipe-line facilities of the country are ample to handle the normal distribution of the current production.³

The significance of the pipe line in the development of the petroleum industry has been great. It has made crude petroleum independent of the railroads⁴ and through cheapness of operation has lowered the cost of petroleum products; it has freed the refineries from geographic allegiance to areas of production and permitted their establishment at strategic points in respect to consumption of products; it has permitted and induced integration of activities, with marked advantage to the consuming public, but not unaccompanied by hardships and abuses falling upon small units of the industry

¹ The approximate mileage of the principal pipe lines of the United States is listed in Committee Print of Departmental Reports on H. R. 3232 and S. 2812, House Committee on the Public Lands, 1918, and sums up to 28,995 miles. The total length of all the pipe-lines is much greater.

² An 8-inch pipe weighs 28 pounds per foot, and its cubic capacity is about 328 barrels of oil a mile. This means that millions of barrels of oil are required merely to keep the pipe-lines of the country active. The cost of an 8-inch pipe-line, on the basis of the costs of materials in California in 1914, is upwards of \$20,000 a mile. (See Report of the Committee on Petroleum, California State Council of Defense, by Thelen, Blackwelder, and Folsom, July 7, 1917, which represents a detailed and valuable study of the petroleum industry of California.)

Pipe-lines are found in foreign oil regions as well as in the United States. In the Caucasus a line connects Baku with the Black Sea, 550 miles distant, passing through a rugged and broken mountainous district. At Tuxpam, one of the oil ports of Mexico, pipe-lines reach out under water for more than a mile, permitting ships at safe anchorage to be loaded.

³ The maximum daily capacity of the principal pipe-lines, as listed in Committee Print of Departmental Reports on H. R. 3232 and S. 2812, House Committee on the Public Lands, 1918, sums up to 1,908,750 barrels, over twice the daily production of the country.

⁴ A very important feature under present conditions, bringing up an obvious comparison with coal, which needs a like emancipation, at least in part. (See Bulletin 102 of this series, Parts 1 and 3.)

itself; and by stretching out to meet a growing area of exploitation it has unified widely separated fields and enabled production to grow to its present imposing size. The pipe line has woven the scattered strands of adventurous exploration into a steady flow of bulk raw material. (See fig. 5.)

Some crude petroleum is transported in tank cars, but most of the 60,000¹ tank cars in operation in this country are engaged in moving petroleum products—gasoline, kerosene, and fuel oil chiefly. For transportation by sea, steel tankers and towing barges, fitted with

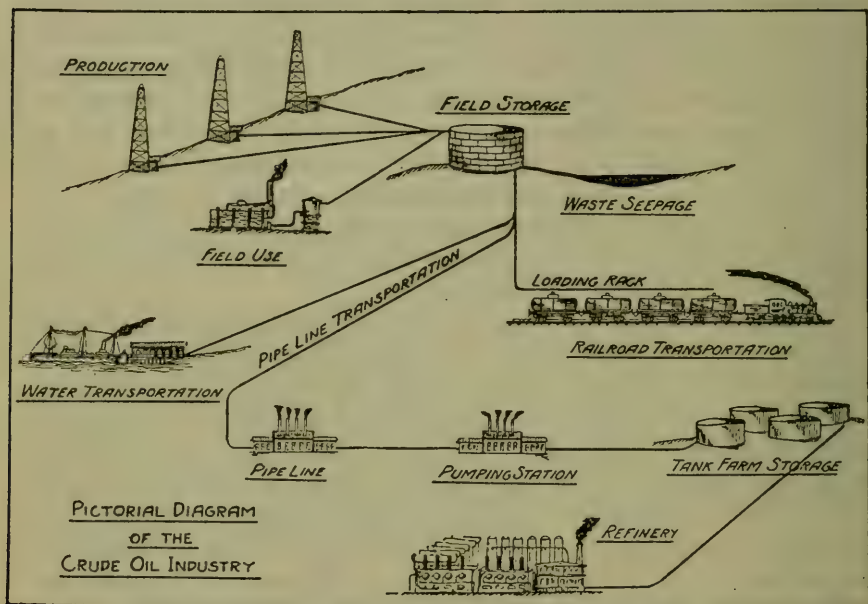


FIG. 5.—DIAGRAM OF THE CRUDE PETROLEUM INDUSTRY. FROM REPORT OF THE COMMITTEE ON PETROLEUM, CALIFORNIA STATE COUNCIL OF DEFENSE.

noncommunicating compartments, are employed for both crude petroleum and its bulk products. The development of the tank steamer has been an important factor in building up an important foreign trade in petroleum products, is responsible for a considerable coastwise movement of crude and fuel oil,² and has opened the oil fields of Mexico to the United States and other markets.

REFINING.

Crude petroleum may be burned as fuel and nearly a fifth of the domestic consumption is utilized in this way.³ But most of the petroleum is manufactured into a series of products which have wider

¹ Approximate number.

² The tanker is the only commercial rival to the pipe line; movements of oil from the Gulf to North Atlantic ports, therefore, normally go coastwise instead of overland.

³ A small proportion of the crude petroleum is used for dressing roads.

usefulness and higher value than the crude oil, and it is upon this dominant part that the petroleum-refining industry depends. The refinery is merely an ingenious mechanical device whereby the raw material, through the agency of physics and chemistry, is fitted into the needs of society. As these needs are ever increasing in size and diversity, refining practice is in continuous flux, adapting a constant substance to a shifting and widening demand.

At the present time petroleum yields, when completely refined, four main products—gasoline, kerosene, fuel oil, and lubricating oil¹—and a large number of by-products,² of which benzine, vaseline, paraffin, road oil, asphalt, and petroleum coke are well-known examples. Most of these products in turn may be broken up into other substances, each the starting point of further refinements. Under present practice petroleum yields only a few hundred substances of commercial value, but the mind can set absolutely no limit to the number of useful materials that chemical research may still wrest from this raw material.

While refinery practice is a highly technical matter and varies both according to the chemical nature of the oil and the local demand for products, we may, for the sake of simplicity, ignore all details,³ and note merely that there are three main types of refineries. The first of these is called a "skimming" or "topping" plant, because the light oils, gasoline and kerosene, are removed from the rest of the products, which are left behind as a residual oil and sold in this semicrude condition for fuel purposes. The "skimming" plant, as its name implies, makes an incomplete recovery of products, supplying only those in greatest demand or easiest to make; most of the plants of this kind are situated west of the Mississippi River.

The second type of refinery may be termed the "straight-run" plant; this produces all four of the main products—gasoline, kero-

¹ These are commercial terms and therefore carry no exact meaning in a chemical sense. They are used throughout this paper with their usual rough significance. Since the products merge one into the other, there can naturally be between them only an arbitrary line of demarcation. As this line has not been precisely fixed, either by commercial usage or by legal standardization, the terms are merely broad expressions of the main fractions into which the crude oil is broken. Gasoline, as here used, covers those products of crude oil which are more volatile than kerosene; the term therefore embraces some benzine and naphtha. Kerosene, as here used, is the common type of illuminating oil representing the distillate heavier than gasoline, but lighter than fuel oil. Fuel oil is used as a broad term, including all distillates heavier than illuminating oils and lighter than lubricating oils; it includes so-called gas oil—a high-grade fuel oil used in the manufacture of gas—as well as fuel oil proper, used largely for steam raising. The term lubricating oil includes a variety of heavy oils used for lubricating purposes.

² The term by-product has no exact meaning, though its significance is clear. For an economic discussion of this matter, consult page 95 of this paper, and Lewis H. Haney, Gasoline prices as affected by interlocking stock ownership and joint cost, *Quart. Journ. Econ.*, vol. 21, pp. 648-655.

³ Such details may be found spread over dozens of pages in standard treatises, such as Bacon and Hamor, *The American Petroleum Industry*, New York, 1916.

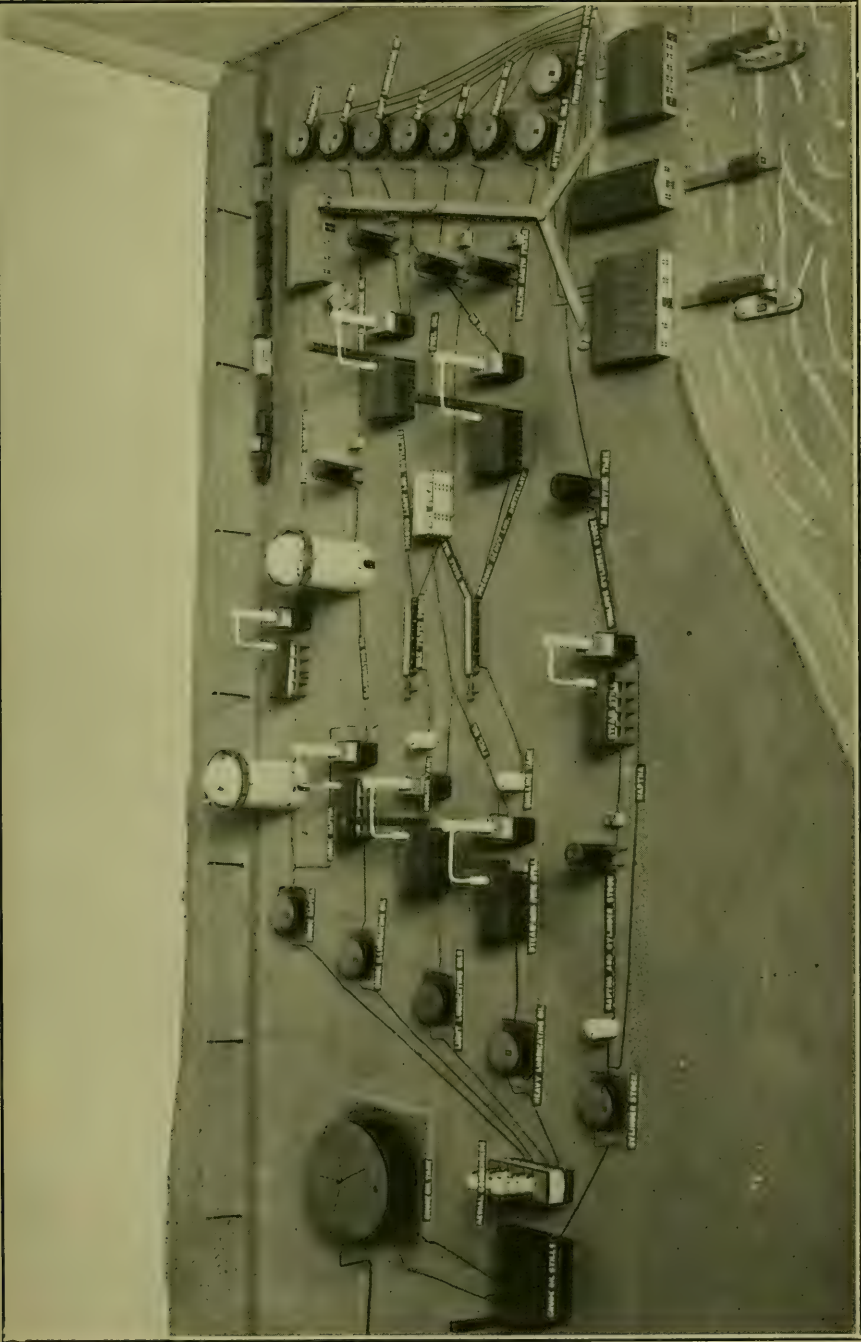
sene, fuel oil, and lubricating oil—together with by-products, the process separating the crude oil into its natural components with the minimum of chemical change. The “straight-run” refinery lacks flexibility, because it has no power of producing, for example, more gasoline than the crude oil naturally contains.¹ Such plants are situated in the East and other parts of the country where the demand, especially for lubricants, justifies the expense of the practice.

The third type of refinery is of recent birth, but has made rapid strides toward a great future; it employs the so-called “cracking” process, which yields, like the “straight-run” plant, a full set of products, but a greater percentage of gasoline than the crude oil gives upon ordinary distillation. This is accomplished at the expense of the heavier component oils, whose molecules are broken or “cracked” into lighter molecules, which constitute just so much additional gasoline. It is obvious that cracking has developed in response to a growing demand for gasoline; its significance is apparent in the fact that it permits the production of a more valuable product from one less valuable. With an increasing call for gasoline and a decreasing supply of petroleum, cracking may be called the hope of the future as regards refinery advance.

If we pause for a moment to contemplate the consumption of petroleum in the crude condition, and then the three types of refining—skimming, straight-run, and cracking—it becomes evident that each treatment represents a step in advance over the preceding, and that, while all four prevail to-day, the cracking refinery is in line with true progress and will eventually dominate the situation.

Refineries, whatever the type, employ the principle of distillation in their operations. The petroleum is heated in stills and the products vaporize, pass off, and are condensed in fractions, representing roughly the materials in demand. These products are then purified by chemical treatment or transformed by chemical means into a series of secondary products. The production of the various kinds of lubricating oils needed for diverse uses represents an intricate, yet single, part of petroleum refining; and is merely one aspect of the many ramifications found in refinery technique. The refining of petroleum makes heavy drafts upon other chemical industries—for example, in normal times, about one-tenth of the sulphuric acid produced in the United States goes into petroleum refining—but the refinery in turn contributes many essential products to other chemical manufacturing activities. These industrial interrelationships, oft-times overlooked, are of the utmost significance—a fact strikingly

¹ Such statements are true in a broad way only; the reader will understand that rigorous scientific accuracy of statement must be partly sacrificed to gain simpleness of expression.



MODEL OF AN IDEALIZED PETROLEUM REFINERY IN THE DIVISION OF MINERAL TECHNOLOGY, UNITED STATES NATIONAL MUSEUM.

From data supplied by Tidewater Oil Company.

brought out when one activity is called upon to expand more rapidly than some other activity with which it is geared.¹

The refining of petroleum, requiring elaborate plants, is by nature a large-scale enterprise; hence such activities in the main have naturally come under the control of a few large organizations.² While several hundred individual refineries are in operation, the bulk of the output is due to the efforts of less than 10 companies. The refining of petroleum, therefore, is largely an integrated activity, in close alliance with transportation of crude, on the one hand, and distribution of refined products on the other. It has already been pointed out that the development of pipe-line transportation has permitted the establishment of refineries at points distant from oil fields, but convenient to centers of consumption and to seaports. Hence one of the largest refineries in the world is at Bayonne, N. J., consuming oil from the interior of the country.

With the broad outlines of refinery technique in mind, it will be of interest to observe the shifting focus of development that has characterized the production of petroleum products in America. When the famous Drake well struck oil on Oil Creek, Pa., in 1859, an illuminating oil distilled from coal and called "coal oil" was in general use throughout the country. Petroleum, therefore, found a market already established for its illuminating constituent, which it usurped at once, quickly supplanting the coal-oil industry with a production of *kerosene*.³ Although other products were also produced and lubricating oils made from petroleum found quick favor in connection with a growing application of mechanical energy, kerosene became the chief petroleum product and for over 40 years its use expanded until this illuminant penetrated literally to the uttermost corners of the globe. It would be difficult, indeed, to estimate the value to the world at large of this cheap and convenient source of light, which has been aptly termed "one of the greatest of all modern agents of civilization."⁴ During this period there was little de-

¹ The apparent failure to recognize and allow for this fundamental principle has been the source of considerable trouble in connection with recent production aspects of the industrial situation in the United States.

² Small plants can not focus on refinements of development, hence they mean resource waste.

³ To this day the term "coal oil" is not uncommonly, though incorrectly, applied to kerosene. Crude oil itself was not adapted to illuminating purposes, but the fact was quickly discovered that a satisfactory oil could be distilled from it; and with the establishment of that fact a great industry was safely launched.

⁴ "All the world loves light, which is so necessary for the reading habit and the spread of civilization, and kerosene made from petroleum is, in every continent, the most common illuminant for the family lamp. For ages mankind had been depending upon vegetable and animal oils. Since remote times the lamps of south Europe have been lighted with olive oil. In northern Europe and America whale oil was more popular, but by the middle of the nineteenth century the demand for this oil had become so great that the whales were well nigh exterminated, and the discovery of abundant petroleum and the art of using it came just in time to prevent a return to the gloom of the tallow candle." J. Russell Smith, *Industrial and Commercial Geography*, 1913, p. 404.

mand for the light products of distillation, the liquids now sold under the commercial name of gasoline, which were, therefore, largely waste products in an economic sense and even in some instances physically

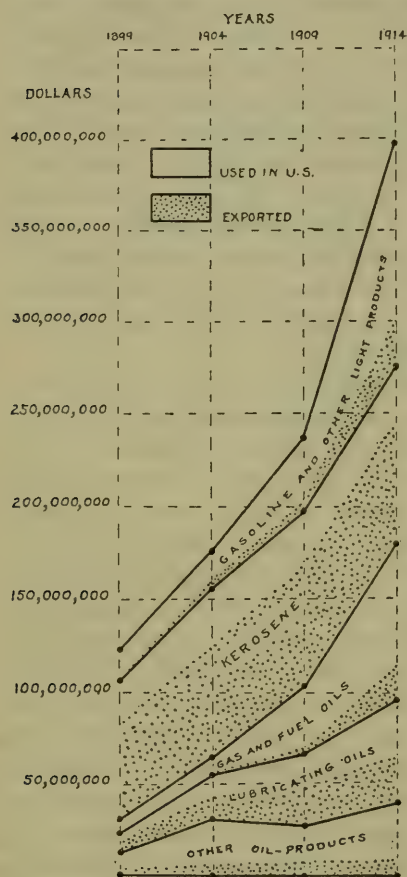


FIG. 6.—CHART SHOWING THE RELATIVE VALUES OF THE PRINCIPAL PETROLEUM PRODUCTS MANUFACTURED IN THE UNITED STATES FROM 1899 TO 1914. NOTE THE DECREASING IMPORTANCE OF KEROSENE IN SUSTAINING THE COST OF REFINING, AND THE NECESSITY OF EXPORTS FOR MAINTAINING A BALANCED OUTLET OF PRODUCTS. DATA FROM STORY B. LADD, PETROLEUM REFINING. CENSUS OF MANUFACTURES: 1914, BUREAU OF THE CENSUS, WASHINGTON, 1917, P. 10.

destroyed for want of any adequate demand for their utilization. Gasoline for a long time, then, was a by-product of little value turned out in the manufacture of kerosene. (See fig. 6.)

Toward the close of the nineteenth century, however, the commercial application of the incandescent mantle in gas lighting and the development of the electric light introduced a type of illumination so superior to the kerosene lamp in convenience that the use of the latter was gradually relegated, in large part, to the small town, the country, and foreign regions, where the introduction of gas and electricity was not possible. Accordingly, in spite of a most aggressive campaign for foreign trade on the part of the petroleum industry, the refinery faced the restrictions of a slowing demand for kerosene which presaged a limit to the output of the whole set of petroleum products. But the menace of this limiting circumstance was destroyed, before it became effective, by the introduction and rapid advance of the internal-combustion engine. The phenomenal growth in the use of the automobile built up such a heavy demand for gasoline that this product came into the lead and took up the burden of

justifying the increasing refinery consumption of crude petroleum—a burden which kerosene, even with the aid of a growing market for fuel oil, lubricants, and other oil products, was scarcely longer able

to sustain. Gasoline now is the main prop to the whole cost structure of petroleum refining.¹

With the industrial quickening due to the entrance of the United States into the world war, the demand for fuel oil² has become so insistent that the complexion of the oil situation has again changed and the emphasis now falls upon fuel oil. And as the production of crude petroleum has not been able to keep pace with the attempted consumption of fuel oil, a serious shortage of this product has resulted; even while the supplies of gasoline have been ample to maintain the activities of war, business, and pleasure.³

If the course of development, as indicated by this broad survey of refinery evolution, be projected into the future, we may foresee a time when the petroleum industry will yield a range of fuels for the internal combustion engine only; illuminating kerosene in quantity narrowing to that desirable for country use and export trade; lubricating oils adjusted to the growing demands of mechanical power; and an ever-widening range of chemical products supporting a great oil by-products industry, rivalling if not exceeding the coal-products industry in importance. In respect to the last, it should be emphasized that the United States to-day faces an opportunity similar to that which 20 years ago confronted both Germany and the United States as regards the manufacture of dyestuffs, explosives, fertilizers, drugs, and other chemicals from the nonfuel components of coal.

DISTRIBUTION.

Many industries terminate their activities with the manufacture of commercial products, turning these over to independent agencies for distribution. With the petroleum industry, however, distribution forms an integral division of the industrial activity, a carefully planned out construction of markets as part of the resource development being substituted for a demand ordinarily left to natural growth or maintained by costly advertising. Thus, once the oil is produced, it passes through the various stages of transportation, refining, and distribution under the influence of a highly organized economic machine, a coordinated industrial unit, engaged not merely in adapting a crude material to diverse uses, but also in shaping and developing latent needs the world over into a demand which will sustain a balanced output of products.

We have already seen how the pipe-line, and to a less extent the coastwise tanker, brings the crude petroleum to the refineries which

¹ For an interesting discussion of this matter, see Report on the price of gasoline in 1915, Federal Trade Commission, 1917, pp. 52-53.

² The demand for fuel oil has been accentuated by an inadequate coal supply and is in part a reflex from that circumstance.

³ Various aspects of this situation will be treated in the section on the war situation, pp. 35-39 of this paper.

are favorably located in respect to distribution. From the refineries the gasoline, kerosene, fuel oil, lubricating oil, and other petroleum products are sent forth to supply the needs of surrounding territory, while refineries near seaboard furnish heavy contributions to foreign trade. As distribution is a diverging process, and, moreover, the crude petroleum is broken into numerous products requiring separate handling, the pipe-line is not broadly adapted to this diverse haulage. Railroad tank cars,¹ therefore, receive the bulkier products and carry them to distributing depots, where storage tanks release the railroad carriers and supply tank wagons that radiate to fill the local needs. In this way the entire country is covered by a network of specialized transportation, each step employing a bulk carrier best adapted to its particular purpose both as to size and mechanical facility, the whole involving the maximum of expedition and simplicity. Without this highly organized system, with its far-reaching ramifications, the present widespread use of gasoline and kerosene would not be possible. From the oil field to the consumer, the handling of petroleum is remarkably efficient.

The arrangements whereby a foreign trade has been built up and sustained are no less elaborate. Fleets of tank steamers and freighters carry the products in bulk or in suitable containers to all parts of the world. Fuel oil, gasoline, and lubricants go in greater measure to industrial countries, but kerosene penetrates to every corner of the globe, a system of depots and distributing lines adapting the product to the needs of the most out-of-the-way regions. The care that has been bestowed upon the extensions of the market for kerosene, against every conceivable obstacle of climate, topography, and racial prejudice, is a striking example of industrial foresight; yet without this policy, the whole oil industry would have been unable to expand to its present proportions.

THE NATURAL GAS INDUSTRY.

Natural gas is produced in large quantities in the United States, partly as a by-product from oil wells and partly from gas wells drilled in oil fields or adjacent territory. Both natural gas and petroleum are of common origin, the former indeed being merely a volatile component of petroleum, occurring either dissolved in the petroleum under pressure or migrated, as result of the advantageous degree of mobility favoring a gas, to positions more or less distant from the petroleum. The gas-bearing territory of the United States, therefore, embraces the productive oil fields and a considerable area besides. (See fig. 3.) Natural gas is won in 23 States, of which West Virginia, Pennsylvania, Ohio, and Oklahoma enjoy the largest commercial yields.

¹ And to some extent barges where water transportation is advantageously available.

The natural gas produced is of two types according to whether it carries a conspicuous burden of gasoline vapor or is lean in this constituent. The first type, as may be surmised, flows from an oil-productive stratum and is called "wet" or casing-head gas, since it makes its appearance from the casing-heads of oil wells. The second type is termed "dry" gas, and comes from portions of porous rock formations practically free from oil; it is produced through gas wells more or less independently of petroleum output.¹

While not vital to the country, because its use may be supplanted by other types of fuel, natural gas is of considerable commercial importance, as shown in the accompanying table:

Relative commercial importance of natural gas, expressed on a per capita basis for 1915.^a

	Consumption per capita.	Value per capita.	Average price.
Natural gas (cubic feet).....	b 6,285	\$1.01	c \$0.16
Artificiality gas (cubic feet).....	1,818	1.65	c .91
By-product, coke-oven gas (cubic feet).....	840	.08	c .10
Crude petroleum (barrels).....	2.8	1.79	c .64
Anthracite coal (tons).....	.9	1.84	d 2.07
Bituminous coal (tons).....	4.4	5.02	d 1.13

^a Figures calculated on basis of population of 100,000,000 from data published in Mineral Resources of the United States for 1915, U. S. Geological Survey.

^b Includes various types of artificial gas as commonly supplied in municipalities.

^c Per 1,000 cubic feet. Note the marked discrepancy in price per 1,000 cubic feet. The intrinsic value, as contrasted to the commercial value, is 1.5-2, 1, and 1 respectively.

^d Price at mines.

About one-third of the natural gas consumed in the United States is used for domestic purposes—lighting, cooking, and heating—while about two-thirds is burned in industrial plants under steam boilers and especially in metallurgical operations, glass and pottery furnaces, and cement kilns, where the requirements of an intense heat call for gaseous fuel. In Ohio and Western Pennsylvania, in particular, the abundant occurrence of natural gas has determined the location and widespread development of gas-fired industries.²

¹The two types of gas are gradational, not sharply distinctive. "Wet" gas carries upwards of three-fourths of a gallon of gasoline per 1,000 cubic feet of gas, while much of the "dry" gas carries only from one to two pints of gasoline per 1,000 cubic feet. See George A. Burrell and others, Extraction of gasoline from natural gas by absorption methods: Bulletin 120, Bureau of Mines, 1917.

²Thus Ohio and Pennsylvania are the two leading States in the manufacture of clay products; the Pittsburgh district is the greatest glass-manufacturing district of the United States, while the iron and steel industry in the vicinity of Pittsburgh consumes an enormous volume of natural gas in its blast furnaces, foundries, and rolling mills. Natural gas has been "the fourth element in making western Pennsylvania more liberally supplied with fuel than any other place in the world. In that region a thick forest covered hills which were underlain with the magnificent coal deposits of the Appalachian field, while farther down was the crude petroleum and the natural gas that drove it spurting from the orifices in the rocks." The rising cost of natural gas, coming with progressive exhaustion of fields, has caused a migration in the glass-making industry, many plants having moved from Pennsylvania to West Virginia and from Indiana to Oklahoma in order to get cheaper fuel; other plants in regions de-

Those activities concerned with the production, transportation, and marketing of natural gas constitute the natural-gas industry. It is largely independent of the petroleum industry, although partly overlapping in production. It consists, in the main, of a large number of independent companies in the form of public-service corporations, although some oil companies market their surplus gas. The drilling of gas wells is not essentially different from that of oil wells; but gas, unlike oil, can not be stored in the field and hence is piped directly to centers of consumption. The gas emerges from new wells under high pressure,¹ but as this declines within a comparatively brief period, the gas field is equipped with compressors which serve to increase the speed and volume of the gas that may be transmitted through gas pipes to distributing stations.

The wastes in natural gas have been appallingly great in the past, and even now, with some of the most glaring points of wastefulness corrected, the resource recovery, by and large, is notoriously small. In connection with the production of oil, especially in fields distant from markets, there has been little incentive to bother with the gas, which has largely been looked upon and treated as a waste product, although now known to be necessary to the proper recovery of the oil. By means of mud-laden fluid, the gas-bearing beds encountered by the oil-seeking drill may be sealed off and the gas conserved for the protection of the oil beds and for subsequent recovery. The gas flowing from the oil-productive stratum along with the oil, particularly in the gusher and youthful period of production, is the casing-head gas from which, since 1910, a growing production of gasoline has been won.

In the gas fields proper, which produce the bulk of the natural gas supplied to cities, the physical wastes which once prevailed have largely been alleviated by correct practice, but there is still economic loss, felt in prospect by the communities concerned, resulting from the circumstance that small leaseholds and competing wells force hasty extraction. This contributes to a general overproduction, leading to an offering of the surplus gas to industrial plants at low rates in competition with coal. Thus, in 1915, the average price of natural gas to industrial users was 10 cents for each 1,000 cubic feet, as contrasted with the average rate of 28 cents charged domestic consumers, a figure none too high as compared with an average rate of

clining in natural-gas yield have turned to producer-gas made from coal, a less satisfactory fuel because not so high in heat value. (See *The Glass Industry*, Miscellaneous Series No. 60, Bureau of Foreign and Domestic Commerce, 1917, pp. 187-188.) The manufacture of carbon black, or lampblack, used in pigments is an industry almost confined to West Virginia, where in 1915 from 19,000,000,000 cubic feet of natural gas there was manufactured 17,000,000 pounds of carbon black, the gas for this purpose having an estimated average value of 2.34 cents per 1,000 cubic feet.

¹ In some instances the pressure is so high, upwards of 1,000 feet to the square inch, that it has to be reduced before piping. In general the pressure of casing-head gas is much lower than that of "dry" gas.

91 cents¹ for artificial city gas scarcely half as good. Since natural gas is the cheapest and most convenient fuel for the home, it seems unfortunate that the limited supply should be squandered for purposes for which coal would suffice.

A full utilization of oil-well gas is dependent upon the course of progress in oil production, as the waste in this connection is merely part of the inferior utilization characterizing the petroleum resource. The proper utilization of "dry" gas, however, involves the elimination of haste-forcing competition among the natural gas companies, which can only come from the control of gas fields by large, well-integrated units, so as to obviate the current overproduction which supports an undue industrial use in regions amply supplied with coal.²

While the production of gasoline from natural gas has been largely confined to casing-head gas, because of its relative richness in gasoline vapor, the recent development of absorption processes extends the possibility to the bulk of the "dry" gas produced. It is conservatively estimated that a gasoline production of 100,000,000 gallons a year could probably be attained in this manner, and a significant start is already under way.³

THE LIMITATION.

We have examined briefly the character and occurrence of petroleum and reviewed in broad outline the industrial activity engaged in the exploitation of this substance. With the magnitude and importance of the petroleum industry in mind, it becomes desirable to observe the portion of the resource not yet used in order to measure its capability toward sustaining a growing responsibility.

THE PETROLEUM RESERVE.

While unmined petroleum, like other mineral resources not exposed to sight, can not be inventoried with a nicety of exactness, the proven and prospective oil fields of the United States are, nevertheless, so broadly known that the petroleum reserves may be estimated within a very reasonable margin of error.⁴ This has been done by the

¹ The price of artificial city gas is much higher than it need be in a revised system of fuel utilization. The cheap supply of natural gas offered industrial users has been one of the factors retarding an effective market for by-product coke-oven gas, thus hindering to a certain measure the adequate development of a coal-products industry in this country.

² Natural gas production under cooperative or organized control could render a more distinct service in emergencies such as the present than it is capable of under current conditions. As a war measure natural gas must be ruthlessly sacrificed as a reserve brought to the aid of coal; but such service should be distinctly temporary.

³ See George A. Burrell and others, Extraction of gasoline from natural gas by absorption methods: Bulletin 120, Bureau of Mines, 1917.

⁴ Few, other than engineers, realized the extent and accurateness of the data bearing on mineral deposits which the rigorously scientific methods of the United States Geological Survey have collected.

United States Geological Survey and the accompanying table shows in simplified form the balance sheet as it stands at present:

Petroleum reserve of the United States, calculated^a to a per capita basis.

	Per capita rate of production (1917).	Mined to date, 1859-1917.	Now underground (1918) and available under present methods of mining.
Petroleum.....	3.4 barrels.....	42 barrels.....	70 barrels.

^a The figures are given in round numbers based on a population of 100,000,000 and are calculated from data presented by the Secretary of the Interior in Senate Document No. 310, 64th Congress, 1st session, Feb. 3, 1916, p. 17, which take into account "the productive possibilities, not only of pools already demonstrated to contain oil, but also of those untested areas in which the geologic evidence is promising."

It is evident from the foregoing table, based on the accumulated knowledge of hundreds of workers in petroleum geology, that an imposing proportion of the petroleum supply is used up. But this table

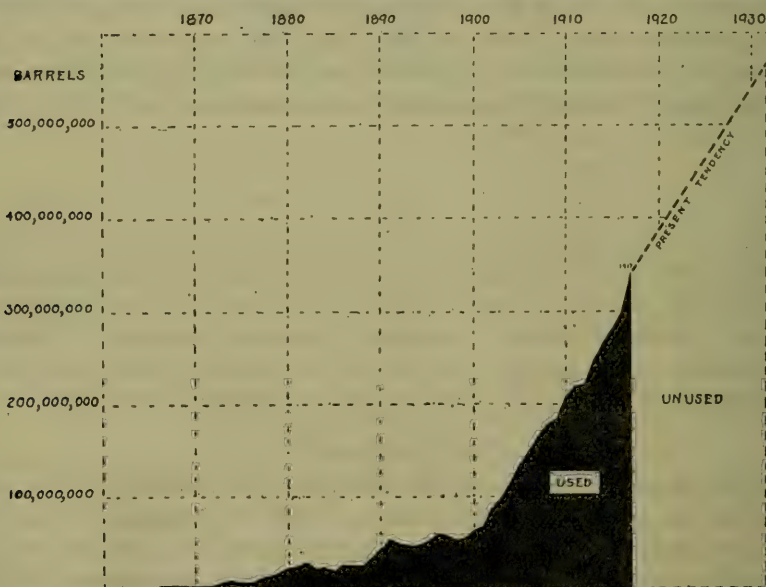


FIG. 7.—CHART SHOWING THE PRESENT TENDENCY OF THE UNITED STATES IN RESPECT TO ITS UNMINED RESERVE OF PETROLEUM. DATA FROM U. S. GEOLOGICAL SURVEY.

does not tell the whole story; the consumption of petroleum, to say nothing of population increase, is growing from year to year at a strong rate, so that a continuation of the present tendency would exhaust the petroleum remaining in an alarmingly short period of time.

This aspect of the situation is depicted graphically in figure 7. With no pretense to prophecy, the diagram expresses the situation that faces the country to-day, and the most generous allowance of margin to cover possible underestimates of future discoveries does

not change materially the nature of the issue. A big fraction of the domestic petroleum is gone; whether that fraction is one-third, as present knowledge indicates, or is one-fourth or even one-fifth, makes no difference in the consideration demanded by the situation. The fact remains that the size of the fraction has meaning to people using petroleum to-day and therefore represents an economic factor that must be reckoned with now.¹

It is, of course, very evident that the present tendency can not persist to the point of even approximate exhaustion,² because conditions naturally arising, such as price increase, growing imports, and others will serve to relieve the tension and thus spread the remaining supply over a greater number of years. So, in spite of its sensational character, the physical exhaustion of the petroleum resource is a theoretical matter of academic interest purely. But of practical importance is the period of economic stress that is ushered in when the resource faces a greater demand than it can fill in the customary manner. That is a period of readjustments to meet the new conditions, and arrives far in advance of physical exhaustion.

As a matter of fact, local adjustments are constantly under way, as petroleum fields reach their climax of production and pass into a period of decline. Thus each field forecasts the history of the resource in its entirety (see fig. 8). These local adjustments affect the industry in the way of causing geographic shifts in activities, but they have thus far had no national effect, because youthful fields have heretofore been ready and able to sustain the shifted burden. But obviously a limit must eventually be reached when an adequate array of youthful fields will be lacking. A consideration of the present situation, in this light, brings forth the realization that such a dominant proportion of our petroleum supply is drawn from the Kansas-Oklahoma and California fields, that their decline can scarcely expect compensation, without development of other fields to a degree to which there is no prospect. It is generally conceded, too, that these two fields have well-nigh, if not already, reached their productive climax (see fig. 8).

It would appear, therefore, that entirely apart from the size of the petroleum reserve, the dependency upon a cumulative oil-field

¹ European countries have repeatedly faced the impending exhaustion of a resource and therefore have gained experience in handling such a situation. But this matter presents an entirely new problem to the United States, and she naturally has no built-up and tried-out machinery for solving it. The average person in this country to-day, or let us say a year ago, apparently looked upon a mineral resource (if he considered it at all) as a clay bank, inexhaustible and to be dug into at will. Consequently, to carry the figure further, our ideas of resource administration as reflected in public policy are excellent for clay-bank resources (and we have some of that kind; i. e., cement, building stone, sand, clay, etc.), but not suitable for those more limited and elusive minerals that must be wrested from the depths of the earth.

² It would appear that complete exhaustion could be achieved by destroying inhibiting economic conditions; that is, by means of extreme measures of socialization, such as fixing a price under a system of forced production.

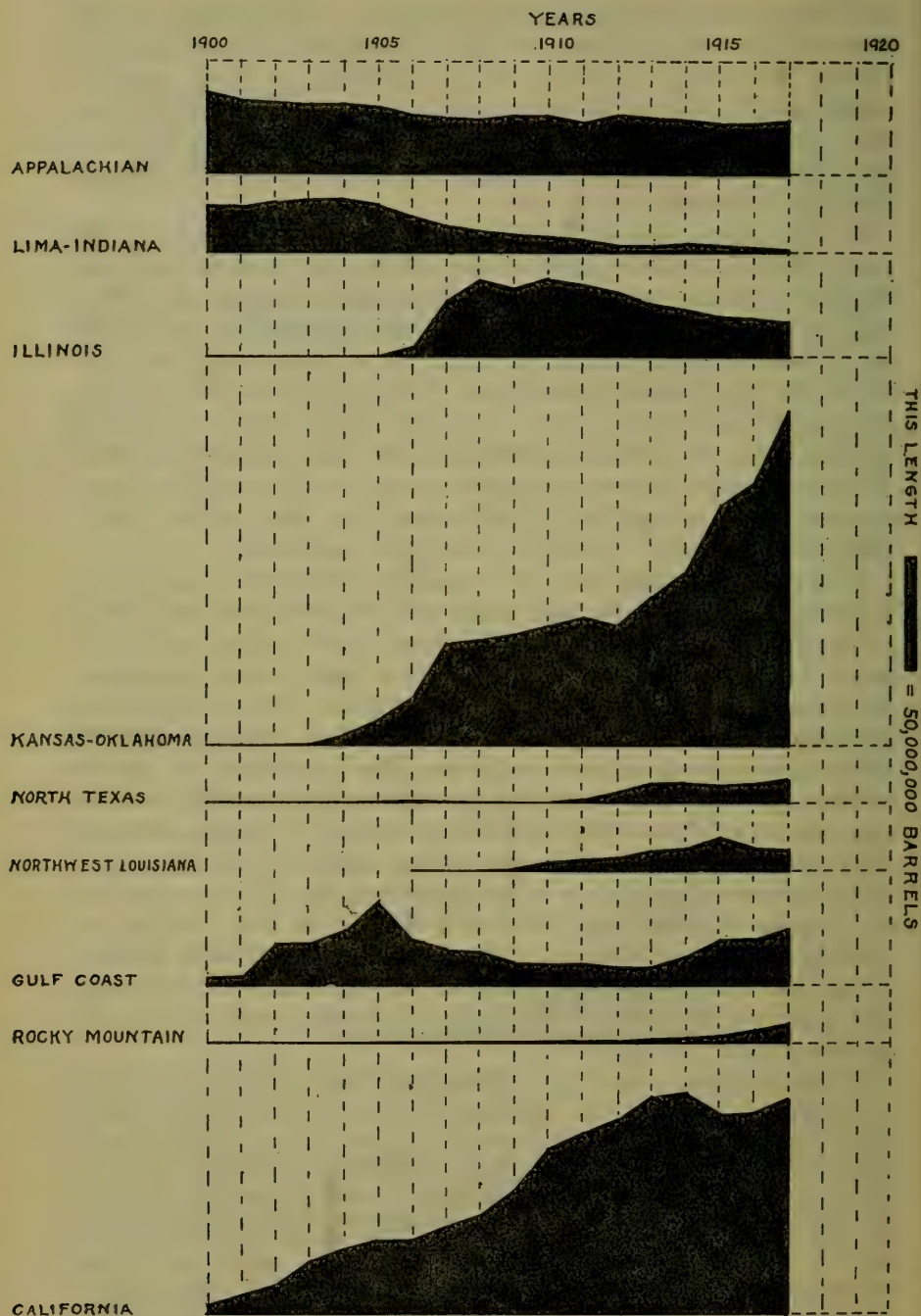


FIG. 8.—THE RELATIVE OUTPUT OF THE PRINCIPAL OIL FIELDS OF THE UNITED STATES FROM 1900 THROUGH 1917. NOTE THE DOMINANT POSITIONS HELD BY THE KANSAS-OKLAHOMA AND CALIFORNIA FIELDS. DATA FROM U. S. GEOLOGICAL SURVEY.

development presages a time, soon to arrive if not already here, when the present rate of production can no longer be sustained in its full vigor. Just so soon as the aggregate output is compounded of senile and youthful fields, with the latter no longer in the ascendancy, the resource as a whole will pass inevitably into a period of slowing and more costly production, even though the resource is yet but half exhausted.¹ The period of economic stress, then, waits merely on this concatenation of circumstances, by no means upon a marked physical exhaustion of the resource.

WHAT PETROLEUM EXHAUSTION MEANS.

It appears from the foregoing section that the petroleum resource is not only strictly limited in size but also in ability to sustain

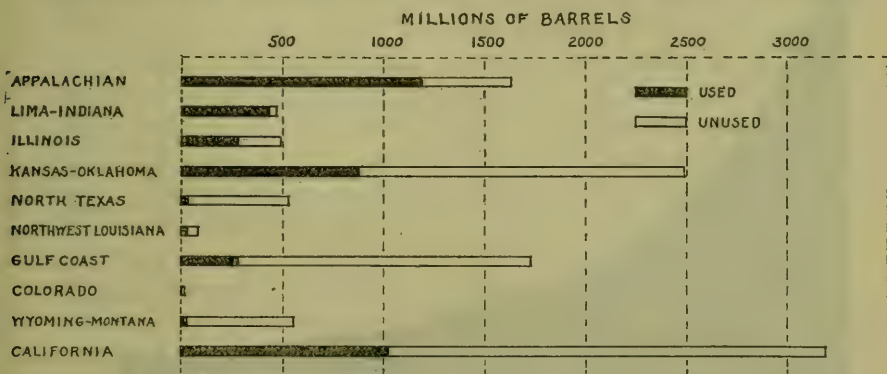


FIG. 9.—CHART SHOWING THE APPROXIMATE DEGREE OF EXHAUSTION OF THE PRINCIPAL PETROLEUM FIELDS OF THE UNITED STATES. THE "UNUSED PORTIONS" CAN BE GREATLY INCREASED BY RECONSTRUCTED METHODS OF PRODUCTION. DATA FROM U. S. GEOLOGICAL SURVEY.

the present rate of increase in production. We may examine, then, what would be involved in a curtailment of activities dependent upon petroleum, since this necessity lies in prospect, in order to be better prepared to weigh the gravity of the issue.

As already noted, crude petroleum² is converted into four main products—gasoline, kerosene, fuel oil, and lubricating oils—and a group of substances less consequential at present which may be termed by-products. The social importance of these five classes of products may be examined in turn, although some of the points have

¹ An oil field in its youth is vigorous; then, in particular, gushers pour forth their exuberance. Later, in maturity and with increasing age, the production is maintained with growing difficulty; many more wells must be drilled; the oil responds less willingly to stronger pumping. Eventually the production declines long before the field is near exhaustion. The gasoline content of the oil also decreases, as a rule, with the aging of the field or pool.

² Apart from the one-fifth, more or less, used in the crude condition, which falls largely into the class of fuel oil.

been intimated earlier in this paper and much of the matter is so universally familiar as scarcely to require even summary treatment. For the latter reason, emphasis will be placed not so much upon the importance of these products as indicated by the past or even the present, as upon their potentialities which the course of affairs are bound to bring out, granted a continued supply. This, in point of fact, is the fairer method, for we are trying to measure off the future significance of petroleum products against the impending inadequacy of the resource.

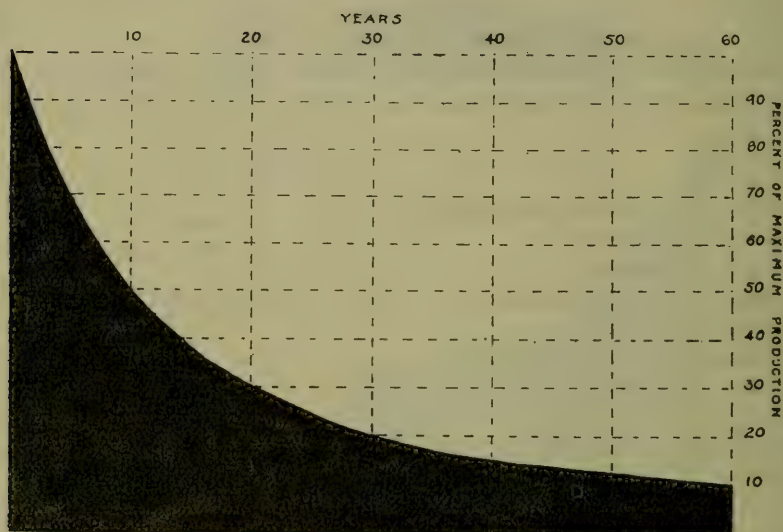


FIG. 10.—CURVE SHOWING THE USUAL DECLINE IN OIL-FIELD PRODUCTION AFTER THE PERIOD OF MAXIMUM OUTPUT IS REACHED. AFTER RALPH ARNOLD, THE PETROLEUM RESOURCES OF THE UNITED STATES, SMITHSONIAN REPORT FOR 1916, P. 283. COMPARE THIS THEORETICAL CURVE OF FINAL DECREASE WITH THE PRODUCTION CURVES SHOWN IN FIG. 8.

Gasoline is responsible for the most significant mechanical development of the twentieth century—the internal-combustion engine.¹ The growing use of this device for generating power, with its great efficiency and adaptability to small movable units, such as the automobile, has colored the whole face of modern civilization. Because of it, a wholly new type of automotive transportation has grown up, at a time when the long-established methods of cumbersome, coal-energized haulage were beginning to impose a serious restriction upon the growth of industrialism and centralization.²

¹ Unless, indeed, the internal-combustion engine has been responsible for the development of gasoline! As a matter of fact, this type of engine was well known before 1900, although its growth has been most striking during the past 18 years.

² The electric motor, of course, has shared with the internal-combustion engine the credit of partly freeing transportation from the restrictions inherent in the necessity for hauling the source of its energy in bulky form. Further turns of this important consideration are followed in Bulletin 102, Part 5, of this series.

The automobile, of course, first by its novelty and later by its wide appeal, has been the prime mover in the automotive development. It would appear to be unnecessary to particularize as to the social value of the automobile, as this matter is common experience. It may be said, however, that apart from its purely luxury use, with which we are not here concerned, the automobile has served to enlarge the possibilities of modern life, not merely by contributing pleasure, but in improving opportunities for physical and mental recreation, social contact, and business activity, with no small contribution toward facilitating the livableness of the modern city. The automobile has gone far on the road toward solving the problem of personal transportation.¹

An important outgrowth of the automobile development has been the motor truck, now used in great numbers for city and suburban delivery service, and coming into prominence in the more populous country districts as an efficient agent for short-haul freight. The importance of this matter is suggested by the fact that the motor truck in 1917 hauled over 60 ton-miles of freight for each person in the United States.² The possibilities of the motor truck are still largely unrealized; its continued extension may be expected to replace largely the short spur line of the railroad; and in connection with the growth of a network of good roads, a country-wide auto-truck utilization will furnish an efficient feeder system to the trunk transportation channels of the country. In respect to the prompt delivery of farm produce, whether to railways or directly to towns, the motor truck has an exceptionally useful opportunity.³ The whole problem of food supply, indeed, is closely bound up with the matter of adequate facilities of transportation⁴ and appropriate use of mechanical power, for both of which petroleum products have a tremendous field of unrealized usefulness.

The tractor for farm use is a still more recent development than the motor truck and the growth in its utilization during the past few years, especially in the Middle West, has been great. Coming into play at a time when the national food problem has taken on a

¹ It is scarcely necessary to point out that the automobile supplements, but does not replace, the standardized service rendered by the steam passenger train and the electric urban and interurban lines.

² This was only a small fraction of the freight hauled by the railroads of the country, whose record in 1915 was 2,768 ton-miles per capita, yet the proportion is important and growing.

³ The horse and mule for small-unit haulage are destined to pass in large measure; they represent an engine consuming high-priced fuel useful otherwise as food, running 24 hours a day whether used or not, and low geared with a capacity of only 3 to 4 miles an hour at best.

⁴ The problem of good roads has never received adequate attention in the United States. A striking example of the intricate interrelationships of industrial problems is afforded by the fact that good roads in part rely upon the use of road oil, which is made both from petroleum and from coal tar, being thus dependent upon the adequacy of the petroleum-products industry and the coal-products industry.

world-wide aspect, the tractor assumes the utmost present importance, while the future demands an extension in its use such as may be expected to largely relegate to the past the old-fashioned methods of hand-power and horse-power tillage. Indeed, upon the growing use of mechanical power upon the farm by means of the tractor, the motor truck, the stationary engine, and the automobile—all dependent upon a cheap and adequate supply of motor fuel—the food supply of the future turns. Farm work must be made more agreeable and more efficient if a growing population is to be fed.¹

The present importance and future significance of the stationary internal-combustion engine, the motor boat, and the airplane need scarcely be touched upon here. As to the last, its use in the present war has led to such a development in flying technique as to justify the expectancy that this speedy and mobile agent will soon come into a growing measure of service and use in the affairs of civil life.²

Back of the widespread utilization of the internal-combustion engine stands a great industry engaged in the manufacture of automobiles, motor trucks, and tractors. Starting scarcely two decades ago, this activity has grown until it now represents the third industry, in point of financial value and importance, in the country. In 1917 motor vehicles of all kinds to the number of 1,814,988 are reported to have been manufactured in the United States, having a wholesale value of nearly \$1,100,000,000.³ As may well be appreciated, the automotive industry, by virtue of the kind and amount of labor to which it gives employment, of its ramifying sales agencies and extensive advertising, and in turn through its use of steel, aluminum, nickel, rubber, leather, wood, and other raw materials, extends its roots throughout much of the industrial fabric of the country. This industry is wholly dependent upon the adequacy of petroleum products for continued growth.

It would appear, then, that curtailment in supply of motor fuel would affect a remarkably wide range of interests. The automobile-

¹ This whole matter is of the utmost importance, with many complexities that can not be gone into here. The agricultural industry should be the greatest of all industries, but instead it is merely a loose assemblage of disjointed, individual activities, with a tendency in many sections to disintegrate further rather than to unify and undergo organization. With some notable exceptions, therefore, it has made little progress toward effectiveness in a broad way—the toll of the farmer is still notorious—and the Government as yet has taken few broad, constructive steps looking toward cooperative developments in farming, confining its efforts thus far largely to polishing off details in the present inadequate system. Fertilizers and tractors, under organized cooperative effort, spell the solution to the food problem—a problem which otherwise will become still more critical within a very few years, whether the war persists or not. It is a curious and pathetic anomaly that the two most basic industries in the United States, the food-production "industry" and the coal industry, are the most inefficiently organized!

² A modern military airplane consumes about 20 gallons of gasoline an hour. The quantity of gasoline for the American fleet in course of construction will amount to several million barrels a year.

³ The *Annalist*, Jan. 7, 1918, p. 10.

owning public, farmers, business activities using motor trucks, and the automotive industry with its ramifications—or expressed in another way, transportation, food production, and a large branch of manufacturing—all have a vital concern in this matter. Under a waning petroleum supply, these various activities would suffer a progressive narrowing in scope which would be the antithesis of the continued progress that their importance urges.¹

In respect to kerosene, we have previously observed that this illuminant has brought a cheap light to millions of people the world over.² This commonplace substance has been America's greatest gift to the uncultured peoples of the globe. With the latter-day development of city lighting, however, the kerosene lamp has been displaced in civic centers, but it still remains the solace of the evening hour among the country folk of this country and the natives of nearly every foreign region. A failing supply would return much of the world to the gloom of the flickering candle, a setback that it is the altruistic duty of this country to circumvent, if consistently possible.

Over half of the petroleum currently produced is used as fuel for steam raising, this portion including the crude petroleum employed for fuel purposes and the fuel oil proper turned out by petroleum refineries. The whole southwestern portion of the United States is wholly dependent upon fuel oil; Pacific coast shipping and naval activities on both oceans draw much of their energy from this substance; and with the progress of war activities a growing number of industrial operations of the eastern half of the country are employing this convenient fuel. While the application of fuel oil to steam raising is an economic perversion, for which the penalty is severe, the fact remains that the United States is, for the time being at least, hopelessly entangled in the necessity of prolonging much of this wasteful practice, an unduly forced reduction of which would be fraught with disastrous consequences, particularly for the Southwest. The use of fuel oil, however, has grown so extensively during the past year that an overburden now rests upon it which will bring an inevitable train of industrial disasters in the coming months, as the supply is wholly inadequate to sustain even the current demand. Unfortunately, the swing away from coal in favor of fuel oil is still continuing.

As regards lubricating oils, we are confronted with the fact that the whole mechanical equipment of modern civilization is dependent

¹ The possibilities of oil-energized automotive agencies are so great and vital that before long it will be looked upon as an inconceivable folly that oil should ever have been used for steam raising, the most glaring economic perversion that this country has ever been guilty of.

² Part of the kerosene produced is also used in stoves for heating and cooking, part is now used in the engines of heavy trucks, and still another part in process of manufacture is "cracked" into gasoline.

upon lubricants made from petroleum.¹ For purposes of reducing friction (i. e., conserving energy), few substitutes are in sight for mineral oils;² vegetable and animals oils, although preferable for certain highly specialized purposes, are unsuited for general employment, as they oxidize and thicken with use, and tend to become rancid and attack the metal bearings which they cover. With the passing of petroleum, mineral lubricants will be manufactured from oils distilled from shale and from coals, according to methods in operation to-day in countries lean in petroleum, as Scotland and Germany.³ At the present time, in the United States, petroleum is produced and manufactured into products far in advance of lubricating needs, which means that the lubricating portion of the resource is being exhausted at a rate dictated by the demand for oil for power generation. Thus the exhaustion of our principal lubricant resource is being accomplished with much greater dispatch than is justified by true necessity, since part of the fuel demand could be filled by means (i. e., coal and hydroelectricity) not involving a sacrifice of potential lubricants.

Finally, in regard to the large array of by-product substances which are manufactured from crude petroleum, it is evident that these products, which to-day have an aggregate value of scarcely 10 per cent of the total output of the petroleum industry, represent a wealth of raw materials, one step removed from the parent, which together have literally an infinite field of growth, except for limitations of supply. Apart from the present importance of oil by-products, which concern such fundamental matters as paint manufacture, road construction, food preservation, and life conservation,⁴ petroleum holds out reasonable prospects of supplying in important amounts edibles, synthetic rubber, and dyestuffs at no distant date, while an intense focus of chemical research on the matter may be expected to yield a flattering return in many additional directions which now can not be wholly foreseen. The accomplishments to date of this kind in the field of coal products are already well known, although even

¹ Writes M. L. Requa (Senate Doc. 363, 64th Congress, 1st session, Mar. 9, 1916, p. 5): "For it [petroleum] there is no satisfactory substitute as a lubricant; its exhaustion spells commercial chaos or commercial subjugation by the nation or nations that control the future source of supply from which petroleum will be derived. There is but one escape, and that is the discovery of some substitute, now unknown, that will as efficaciously and economically lubricate the machinery of the Nation. * * *"

² Roughly, one-half pint of lubricating oil is required for each ton of coal made into power. Castor oil offers interesting possibilities as a lubricant.

³ There is reason to believe that Germany is suffering a serious shortage in lubricating oils, a dearth which she is only in part relieving by the use of oils made from the distillation products of coal. (See *Nature*, Jan. 24, 1918, p. 414.) Should circumstances arise under which the petroleum fields of the Caucasus are threatened, the critical bearing of this juncture, as offering to Germany the prospect of an adequate supply of lubricants and other petroleum products, should be held clearly in mind by the allied countries.

⁴ The use of petroleum products in medicaments and of paraffin in treating burns are interesting examples.

yet the United States is not taking adequate advantage of its possibilities in this respect; oil by-products afford perhaps even a greater opportunity than stretches out from coal products, but with the difference in respect of the former that the trail is as yet scarcely blazed.¹ It would not be an exaggeration to say that oil by-products represent one of the foremost industrial opportunities that confront the American Nation to-day.

In this connection an interesting vision opens up as to how a great oil by-products industry, through the values accruing to successive refinements of products, may be led to contribute more than it now does to the expense of petroleum production, relieving to that extent the cost distributed among the products universally used in bulk such as gasoline. It would seem that a farsighted economic policy, properly directed, might eventually contribute to a lowering cost for motor fuel, just as a proper shaping of coal economics could be made to relieve the focus of expense now exclusively borne by fuel coal—the two conspiring to lower the cost of living.

THE WAR SITUATION.

The latent weakness of the petroleum resource became apparent under the influence of war stress. By encouraging the petroleum demand without being able to stimulate the supply in like degree, the war merely brought into the immediate present an issue under way and scheduled to arrive in the course of a few years. The war, therefore, permits us to observe the weak points in the resource development as experienced facts, instead of in the light of logical deductions even one stage removed from observation. In short, the war brings the petroleum issue to a head, making the whole problem of the resource a problem of the present emergency also.

The importance of petroleum to modern warfare is obvious and needs no detail here. It is natural that the American resource played an important war-time rôle and in turn has been strongly influenced by the martial situation.²

The outbreak of the European war in 1914 found the petroleum industry of the United States suffering from a period of low prices and depression occasioned by a gross overproduction in the Mid-Continent field, due principally to the remarkable yield of the notorious and unexampled Cushing pool³ in Oklahoma. The demoralization of the normal course of international commerce also added a

¹ A good picture of the problems facing the petroleum industry is painted by Bacon and Hamor, *The American Petroleum Industry*, 1916, pp. 798-806.

² A good account of the war reactions of petroleum is given by John D. Northrop, *Our mineral supplies: Petroleum*, Bulletin 666-DD, U. S. Geological Survey, 1917.

³ This pool, from June, 1914, until April, 1915, when it attained a maximum production estimated at 300,000 barrels daily (over one-third of the output of the entire country), dominated the petroleum industry of the whole United States.

destructive element to the marked abnormal conditions affecting the industry, but readjustments in foreign trade were quickly effected and the unfavorable consequences of external circumstances were not long continued or far-reaching. Toward the end of 1915, owing to the declining output of the Cushing pool, to the acquisition by a few strong companies of a vast accumulation of surplus petroleum in the Mid-Continent field, thus withdrawing it from the open market, and to the general increase in automobile consumption of petroleum products, a tension between supply and demand developed which set prices on a steady climb, renewed confidence in the situation, and started a phenomenal wave of wildcat exploration in search of new supplies. This impetus met with a quick and successful response in the way of output; so much so indeed that the latter part of 1916 saw a measure of overproduction, with consequent price depression; less marked, however, than the sustained period of 1914-15. This second slump was a passing incident, for the demand for petroleum was too insistent to be met with continued ease. The advent of 1917, then, saw prices and demand again on the upward grade and at a height overlooking the attainments of the past.

With the entrance of the United States into the war in April, 1917, it became very evident that the petroleum fields of the country had an important, and at the same time, difficult rôle to play—important, because an enlarging demand was in prospect to maintain the industrial and military activities of the allied cause; difficult, because production, hampered by a growing complexity of circumstances and already shoved to an extreme of activity by favorable prices, presented no prospect of filling the total demand, with little chance of the margin being covered by a growth of imports from Mexico.

As a result the petroleum resource to-day faces a demand that it can not meet. This situation is depicted graphically in figure 10. It may there be seen that the relations of 1917 can not be sustained throughout 1918 without the arrival of critical conditions, and a continuation through 1919 is impossible. The United States is now (Aug., 1918) consuming and exporting more petroleum than she is producing from her own wells and receiving from Mexico. The discrepancy, which is growing from month to month, is covered by a draft upon the petroleum storage in this country, the amount on hand January 1, 1918, being about 153,000,000 barrels.¹ And while

¹ It may be pointed out that this storage can not safely be reduced below a certain minimum figure, say 50,000,000 barrels, needed to fill the pipe lines and keep the whole industry in course of operation.

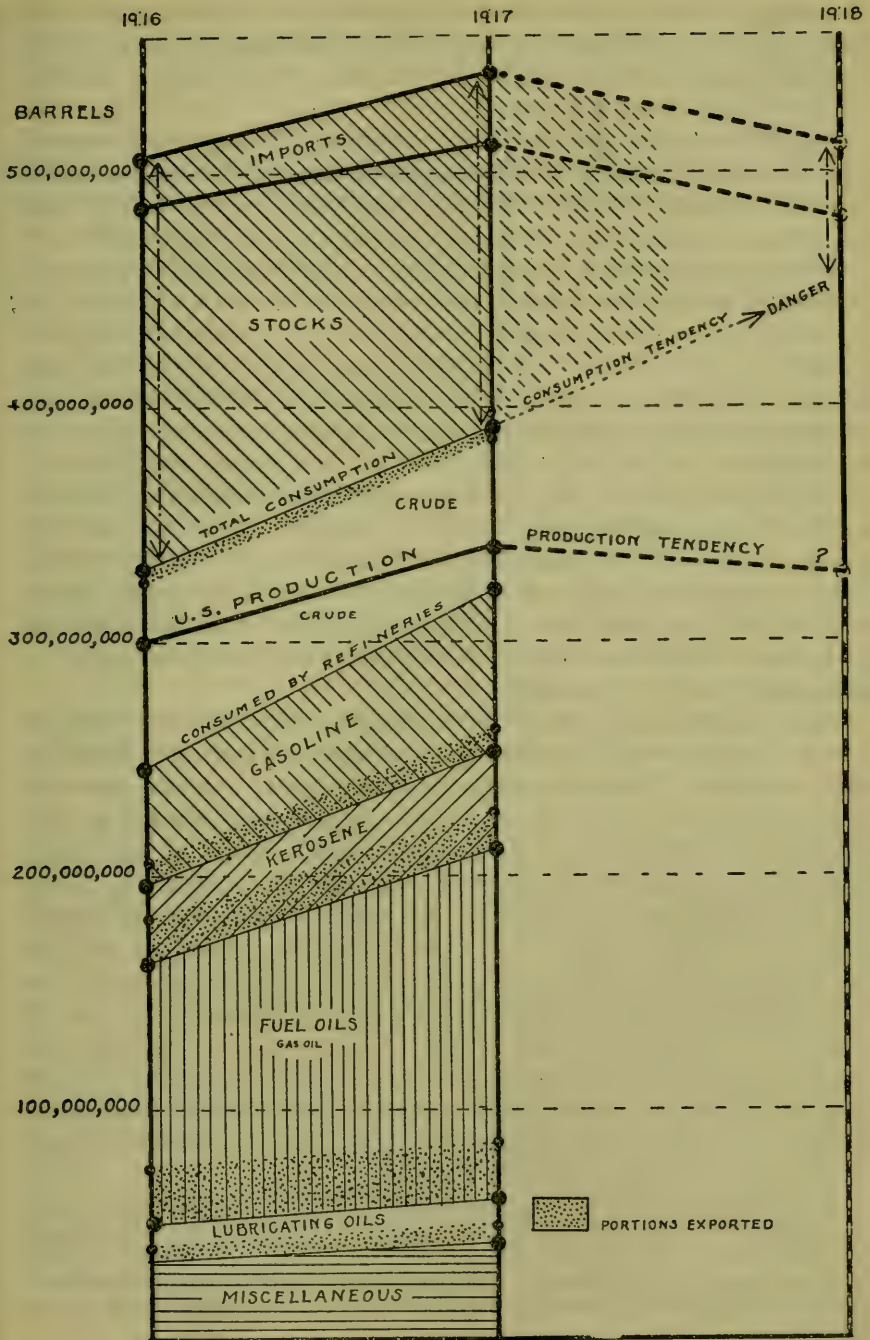


FIG. 11.—THE CURRENT PETROLEUM SITUATION IN THE UNITED STATES. DATA FROM U. S. BUREAU OF MINES, U. S. GEOLOGICAL SURVEY, BUREAU OF FOREIGN AND DOMESTIC COMMERCE, AND OTHER SOURCES. PREPARED IN FEBRUARY, 1918.

the total demands for petroleum are increasing at a growing rate, the rate of production is slowing and there is scant hope of soon increasing the supply from Mexico.¹ In fine, the resource is not equal to all the demands looking to it.

We may examine in closer detail the trend of the growing demand for petroleum. As a result of the general speeding up of industrial activities, especially during the past year, there has not merely come an increased demand for all the petroleum products, but this demand has been preferential, focusing with particular intensity upon fuel oil. Especially has this tendency been marked in the eastern part of the country, the far West already having long been almost entirely dependent upon oil fuel. The growing use of fuel oil in the East during 1917-18 was partly, if not primarily, a reflex from the coal shortage.² Many industries, finding coal difficult or impossible to obtain, turned to fuel oil, which for the time being was "easier" than coal, due to the enterprise and superior distribution organization of the petroleum industry as compared with the coal industry, hampered by more critical limitations in transportation. Even to-day there is reason to believe that many enterprises under construction are planning on oil fuel in place of coal, while among established industries a shift from coal to oil has been going on to an extent not generally realized.

Thus coal shifted part of its burden to petroleum and there is now a shortage of fuel oil, with good prospects of a critical dearth of this substance. While such matters are not open to accurate measure, it is roughly estimated that this shift has relieved upward of 10,000,000 tons of coal during the past winter, much of that generosity being displayed in the very heart of the coal regions. That has happened even in Pittsburgh, the center of the most important coal district in the world. It is evident that such relief can only be temporary, and a continuation will soon lead, if it has not already, to more serious difficulties and eventually to a disastrous breakdown of fuel supply. It is absolutely essential to turn the tide back toward coal in the instances in question, with the possible exception of New England, where the change, due to peculiar transportation conditions, is valid. If coal can not meet the issue, then industrial activities must be curtailed. There is no other way out.³

As the demand for fuel oil for some time has been in advance of the demand for gasoline and other petroleum products, there has been

¹ If transportation from Mexico to this country can be facilitated by the construction of concrete tankers or otherwise, the situation may be considerably eased for the time being.

² It has been influenced also by increased naval and military needs.

³ It is interesting that the most conspicuous maladjustment in the normal utilization of petroleum—the use of oil for steam raising—should have become the point of greatest weakness under war conditions. But such outcomes are inevitable.

no critical dearth of the latter, as they, or at least gasoline, must be turned out in quantity to support a growing production of fuel oil. This is why there was plenty of motor fuel at the time when there was a shortage of fuel oil. This also explains why it was unwise at the outset to cut down on the use of unessential automobiles as a measure of petroleum conservation; that action would merely have destroyed a market for gasoline, which supports the price-structure of petroleum, without being able to materially increase the bulk of the fuel oil turned out. With increasing stress, however, it became necessary to pare down on gasoline consumption, but only as an accompaniment to a similar procedure for fuel oil.

The stimulation of domestic petroleum production to the utmost degree, the alleviation of labor difficulties and shortage of materials affecting oil-drilling, and the solving of shipping problems concerning coastwise and Mexico-to-United States movements of oil, are all matters of the greatest importance, which are receiving the active attention of the Government. It is not the function of this paper, which is concerned with a general economic study of the resource, to treat of these matters or presume even to suggest wherein the solution of the current problems lies. The war situation is here touched upon only in the belief that it illustrates unmistakably the unsoundness of the loose way in which the resource has been drawn upon, and points to the necessity for measures, not merely of alleviation, but of reconstruction in regard to the exploitation of the resource.

THE PROBLEM.

Sufficient, perhaps, has been set forth to indicate that the petroleum industry is not a separate activity to be dispensed with if necessity arises, but that its products are essential to the vital needs of the Nation. Indeed, it would scarcely be too much to say that the whole future of civilization depends upon a continued supply of motor fuel and lubricating oil, while the oil by-products potentiality holds out the prospect of presenting to the world, through the energies of this country, a gift even greater than kerosene has been. It would appear to follow, therefore, that these affairs should not be hampered or curtailed, if in any way the resource or its equivalent may be made to carry the responsibility well into the future. It is a matter of universal concern, then, to inquire if the impending exhaustion of the resource may be circumvented by modern scientific and technical knowledge; and if so, to ascertain the best procedure whereby this constructive force, as yet not fully used in this country, may be brought into effective action.

Granted that curtailment of activities fundamentally dependent upon petroleum is undesirable,¹ we may pass in review the means

¹ This does not apply unqualifiedly to fuel oil used for steam-raising purposes, as shown on page 61.

whereby the capacity of the resource may be enlarged so as to postpone or obviate the necessity for such curtailment. These means will be examined without special reference to their immediate availability under current economic practice, reserving for the next section consideration as to how the most important of them may be brought into effective play.

The enlargement of the resource capacity may be brought about in three ways: By prolonging the life of the unused portion of the domestic resource as it is now known; by developing low-grade domestic sources not yet drawn upon; and by building up the use of substitutes, particularly for gasoline, upon which a heavy and growing demand is falling.

PROLONGING THE LIFE OF THE PETROLEUM RESERVE.

The supply of petroleum unmined is so limited that the maximum should be obtained from it in order to prolong its availability. The enlargement of the reserve through the discovery of new oil fields, the elimination of wastes, and the extraction of a greater measure of service from the products represent the lines of progress in sight.¹

Discovery of new oil fields.—While much of the oil-bearing territory of the United States is still undrilled, there is no hope that new fields, uncounted in our inventory, may be discovered of sufficient magnitude to modify seriously the estimates given. The reasonableness of this assumption will appear from considering the fact that between 1908 and 1916, during which time the most active exploration campaign in the history of oil development was carried on, the reserve was enlarged by only 1,200 million barrels, a scant three years' supply at the present rate of consumption. This means that the petroleum resource of the country, like the coal resource, is now fairly accurately measured; and it would be vain to expect a significant increment from an unforeseen direction. Of course, new strikes and oil booms are to be expected, but these will lie for the most part within the area already represented in our measure of the petroleum reserve.

Elimination of wastes in production.—Far more may be accomplished in the way of enlarging the reserve by the elimination of unnecessary wastes in connection with production.² Under present

¹ The bearing upon the matter of the oil fields of Mexico and Central America is discussed on pages 76, 77.

² An effective and readable description of the physical wastes involved in oil production under present practice will be found in the Yearbook of the Bureau of Mines, 1916, by Van H. Manning, Washington, 1917, pp. 116-133. The technological investigations of the Bureau of Mines have been of the highest value to the industry in the way of supplying the technical means whereby these wastes may be combated. The ensuing paragraphs under this heading are largely a record of the accomplishments of the Bureau of Mines in this connection.

practice, from 90 to 30 per cent of the oil is left underground.¹ Then, of the quantity produced, an appreciable percentage is lost by fire, and a significant portion dissipated by seepage and evaporation due to inadequate storage facilities.² On the average, therefore, it is safe to say that less than 25 per cent of the petroleum underground reaches the pipe line. If we subtract from this proportion the losses involved in improper and wasteful methods of utilization, the recovery factor becomes perhaps as low as 10 per cent.³

Knowledge of petroleum technology is far in advance of its application to oil production, due to the fact that this country is actively engaged in producing such knowledge, but has at the same time provided no adequate machinery for putting this knowledge into play, once it is produced.⁴ Of course part of this advance gets into action where the gain from such application accrues to specific interests, but by and large there is a marked underconsumption of technological science, the discrepancy being often credited, though with questionable validity, against the difference between theory and practice. We may review some of this technological knowledge already in stock, having in mind that the supply is rapidly increasing.⁵

¹ "Estimates of the total amount extracted range from 10 to 70 per cent, 90 to 30 per cent being left in the ground."—Van H. Manning, Yearbook of the Bureau of Mines, 1917, p. 127.

"It is universally acknowledged that by the usual production methods much oil is left underground, the general opinion being that at least 50 per cent of the oil in a field remains unrecovered when the field is abandoned as exhausted. From the writer's own investigations he believes the average recovery is even less * * *"—J. O. Lewis, Methods for increasing the recovery from oil sands, Bulletin 148, Bureau of Mines, 1917, p. 7.

² Evaporation robs petroleum of its lighter components (i. e., gasoline), hence the value loss is much greater than is apparent from the bulk removal.

³ This is not to be taken as an exact figure, but merely as a rough expression of magnitude. No one, of course, can estimate such a matter closely. Twenty per cent would certainly be too high; 10 per cent, therefore, is not far from the true proportion and is a very salutary figure to accept.

"What effort have we made to conserve this supply and to utilize it to its greatest advantage? We have made little effort until very recently to do these things. We have been wasteful, careless, and recklessly ignorant. We have abandoned oil fields while a large part of the oil was still in the ground. We have allowed tremendous quantities of gas to waste in the air. We have let water into the oil sands, ruining areas that should have produced hundreds of thousands of barrels of oil. We lacked the knowledge to properly produce one needed product without overproducing products for which we have little need. We have used the most valuable parts of the oil for purposes to which the cheapest should have been devoted. For many years the gasoline fractions were practically a waste product during our quest for kerosene; with the development of the internal-combustion engine the kerosene is now almost a waste product in our strenuous efforts to increase the yield of lighter distillates." (Yearbook of the Bureau of Mines, 1916, Washington, 1917, p. 117.) If we add to this quotation the statement that gasoline is now almost a waste product in our efforts to make fuel oil help out a bad coal situation, the picture will be true down to April, 1918.

⁴ An analogous situation would obtain if laws were made with no provision for putting them into execution.

⁵ The treatment here, of necessity, merely touches on the more significant features. For details the reader is referred to the numerous publications of the United States Bureau of Mines concerning this matter.

The two greatest wastes connected with oil-well drilling are caused by the harmful infiltration of water from water-bearing strata and the uncontrolled escape of natural gas encountered in the course of drilling. Water is a formidable enemy to oil extraction; as the position of the oil depends, in part, upon a nice equilibrium between oil and water, the undue influx of water into the drill hole means a reduced recovery of oil, if not a total loss of the well; and not only may a single well be completely ruined by inadequate protection against water, but what is more grave a whole field of operations may thereby be spoiled. The damage done in the past by water is immeasurable and largely irretrievable, but the danger from water may be controlled by means of a method of cementation already employed with success in California and Texas, whereby a water-tight band of cement is forced into the space between the well casing and the water-bearing stratum.

Many wells in sinking penetrate gas-bearing formations, and in such instances it has usually been customary to suspend operations while the gas escaped into the air, so that the pressure might be relieved against which continued drilling was difficult or impossible. The actual waste of gas due to this circumstance has been first and last enormous, amounting to billions, if not trillions, of cubic feet, with a fuel equivalent of millions of tons of coal; indeed, it would be safe to say that over half of the natural gas developed to date has been made no use of whatever.¹ But this physical waste, great as it has been, is of small consequence as compared with the waste of the energy represented by the gas-pressure, the dissipation of which leads to a reduced and more difficult recovery of the oil. The gas, therefore, is not only substance but energy, and represents a force which must be conserved for the sake of later gaining a proper petroleum yield. It is rather interesting that the waste of oil and gas involved in the premature production of gas may be prevented by comparatively simple means; namely, by drilling in a medium of mud-laden fluid which serves to encrust the critical parts of the drill-hole, sealing off the formations so that there is no improper escape of gas and preserving the conduit intact down to the productive stratum.²

After the oil is struck, there are many methods for controlling the output so as to avoid the waste incidental to much of the current practice. The flow may be controlled by rather elaborate mechanical

¹ See R. S. Blatchley, *Waste of Oil and Gas in the Mid-Continent Fields: Technical Paper 45, Bureau of Mines, 1913.*

J. O. Lewis and W. F. McMurray, *The Use of Mud-Laden Fluid in Oil and Gas Wells: Bulletin 134, Bureau of Mines, 1916.*

² This process is described in detail in *Bulletin 134, Bureau of Mines, 1916.* There are numerous details of drilling practice which are subject to improvement, but these need not be gone into here.

devices, preventing an overproduction;¹ gushers "gone wild" may be capped and brought under subjugation; "blow-outs" may be guarded against and prevented; and losses due to fire, seepage, and evaporation largely nullified through adequate development of storage facilities. All these gains will accrue more fully through widespread application of well-known engineering technique already successfully practiced in many instances.

The gas that almost invariably comes forth along with the oil customarily carries some of the lighter components of the oil itself. These components are recoverable by means of appropriate methods in the form of a very volatile gasoline, which can be blended with a heavier petroleum distillate to form commercial gasoline. Until a few years ago, the recovery of the gasoline suspended in natural gas was neglected, but now a very significant yield of this so-called "casing-head" gasoline is obtained.² The natural gas is made to yield up its gasoline either through compression, which squeezes out the liquid content, or by absorption, which entices it out by means of a certain type of oil which later is heated and thus forced to yield up in turn the gasoline absorbed.³ Even with full gasoline extraction, however, there remains in many fields much more gas than can be consumed by legitimate demand, which necessitates a waste of the surplus, unless it can be cheaply transported to points where demand exists.⁴ In this connection possibilities open up in connection with processes of liquefaction, by means of which the gas may be compressed into reasonable bounds for transportation.⁵

Due chiefly to the decline of pressure upon the escape of natural gas, wells quickly mature and then produce at a declining rate; but recent investigations go to show that even when a well is apparently exhausted, its full quota of oil has by no means been exacted. On the contrary, as demonstrated by established practice in Ohio and elsewhere, an additional yield may be forced by means of compressed air or its antithesis, a vacuum. The more promising of the two methods consists in forcing compressed air down to the porous oil-bearing formation, thus driving the oil to positions reached by pumping wells. The full possibilities of these methods may not be safely forecast, but they are certainly capable, if widely applied, of increasing by a large

¹ Thus, for example, the flow from Mexican oil wells is at present held down to the transportation capacities available for export, avoiding a tremendous local overproduction.

² Production of gasoline from natural gas has grown from 7,000,000 gallons in 1911 to 104,000,000 gallons in 1916.

³ The absorption method is especially adapted to "dry" gas lean in gasoline vapor.

⁴ When the natural pressure is insufficient or distances too great, the normal transportation through pipes is unprofitable.

⁵ See I. C. Allen and G. A. Burrell, Liquefied products from natural gas: Technical Paper 10, Bureau of Mines, 1912.

percentage the future yield of the country over the estimates made under current practice.¹

It would seem, then, that the wastes in connection with oil production, which are exceedingly heavy, are more due to inadequate utilization of technical knowledge than to lack of means for effecting the economy. To gain a greater return from the resource, then, is more a matter of shaping a proper economic situation in respect to its exploitation than it is a matter of technological research.

Greater extraction of values.—We have seen that the oil in sight in the United States can not be reasonably expected to undergo significant enlargement through new discoveries of oil-bearing territory. The main hope of prolonging the life of the resource, therefore, lies in the two-fold direction of applying improved production technique, as already noted, which will, let us say, double the resource, and of gaining a fuller measure of value from the oil extracted, which is capable of multiplying the resource again by another factor no less great. Improvements in value extraction from the petroleum output will come through the extension and further improvement of "cracking" methods of distillation; through improvements in the design and efficiency of the internal-combustion engine; through the widening use of the Diesel type of engine, thus gradually deflecting fuel oil from its illegitimate rôle of a steam-raising understudy to coal; and through a carefully planned program for building up a great oil by-products industry to give multiplications of value to the portion of oil left after the energy, light, and lubricating values are extracted.

The "cracking" method of petroleum distillation has already been adverted to as representing the most promising means in sight whereby the growing demand for gasoline can be met from a slowing production of crude petroleum. The principle, therefore, is of the utmost importance, since it can be made to shove into the future the most threatening limitation to the growth of the automotive activity. Many "cracking" processes have been developed, all giving the same result, namely, a larger yield of gasoline at the expense of heavier components; but two of them stand out with especial prominence. These are the Burton process, for many years in successful practice in the refineries of the Standard group; and the Rittman process, recently developed by the Bureau of Mines and now also established on a commercial basis.² There is no need here to go into the technical differences between these processes; the prin-

¹ For example, the petroleum reserve is 7,000,000,000 barrels, with a valuation on the basis of 1915 prices of \$4,500,000,000. For each 1 per cent gain in extraction there will accrue to the reserve 70,000,000 barrels, worth \$45,000,000. Expressed in another way, a 60 per cent gain in extraction efficiency will yield the equivalent of the total oil production to date in this country.

² See Rittman, Dutton, and Dean, *Manufacture of gasoline and benzine-toluene from petroleum and other hydrocarbons*: Bulletin 114, Bureau of Mines, 1916. See also *Yearbook of the Bureau of Mines*, 1916, Washington, 1917, pp. 131-133.

ciple is the matter to which emphasis is called. "Cracking" is the leading potentiality in petroleum refining, no less so because it permits the production of the other main products according to demand, without sacrifice of by-product possibilities.¹ The importance of the whole matter may be evaluated by having regard to the fact that at present, even with "cracking" well launched into practice, less than one-half of the petroleum produced is manufactured into products representing an ideal apportionment² of the raw material into its components.³ The production of gasoline may be doubled eventually or even more greatly multiplied without increasing the production of crude petroleum.⁴

The internal-combustion engine of the type currently in use in the United States has been the subject of greater refinements in special qualities—luxury qualities—than in respect to efficiency. That is evidenced in the widely varying gasoline consumption on the part of the familiar brands of automobile motors, which show a range from 20 miles and more to the gallon down to a yield of only 6 or 8 miles in the case of high-price cars. While the sacrifice of efficiency in favor of special qualities is, perhaps, legitimate to a certain degree, it would appear that the desire for invidious distinction has led to an undue focus of attention away from utility. With the rigors born of resource limitation—a certain eventuality—and upon the passing of the automobile more fully from the realm of a luxury into that of a necessity, a greater and more universal reach toward motor efficiency may confidently be counted on. But improvements in motor design will not lie along the single line of gaining more energy from gasoline; the effective use of heavier petroleum distillates, such as kerosene⁵ and fuel oil, and of other liquid fuels, such as alcohol, benzol, and tar oil, will be planned for and the broad trend of motor development will shape toward the character of the resource in its

¹ It should be clearly held in mind that "cracking," with its attendant by-product possibilities, is a matter in constant course of development. The Bureau of Mines is actively engaged in furthering research and experimentation along those lines, though progress is hampered by inadequate financial resources.

² An ideal apportionment can not be attained so long as there is an overproduction of crude petroleum in respect to the demand for gasoline and other motor fuel, kerosene, and lubricating oil, and there remains an economic demand for such an overproduction. Hence the extent to which "cracking" may be applied is, of course, limited by economic factors.

³ "We are to-day using efficiently—that is, for gasoline and lubricating purposes—not more than 30 per cent of our oils. The other 70 per cent is used in competition with coal or exported for foreign countries and is generally sold for less than cost of production." Yearbook of the Bureau of Mines, 1916, Washington, 1917, p. 133.

⁴ "Cracking" brings in the asphaltic oils as effective producers of gasoline, a fact of no small economic significance.

⁵ "Perhaps no phase of the fuel situation has so interested automotive engineers as the use of kerosene in place of gasoline. Present market conditions are such that kerosene is one of the cheaper petroleum products, and as it has already been demonstrated to work satisfactorily in internal-combustion engines under certain conditions, there has been a great desire to render it available for general use in automobiles. The Bureau of Mines has had called to its attention many devices for the utilization of kerosene, but believes that mechanical development in this particular line is a mistake. The logical and reasonable way to utilize kerosene is not as such, but as a mixture with

entirety—a bent as yet only dawningly perceptible. Whether radical changes in motor principle are in prospect is a question that need not affect the present argument.

In point of bulk nearly three-fourths¹ of the petroleum consumed in the United States goes into the production of power. Of this amount, one-quarter¹ is employed in the form of gasoline as a motor fuel,² while three-quarters,¹ in the form of crude petroleum and fuel oil, is used as a convenient substitute for coal chiefly in firing steam boilers.³ While the efficiency of the internal-combustion engine is much greater than the steam engine, now commonly referred to as “wasteful” in comparison with more modern types of power generation, the use of the superior principle has thus far been confined in this country almost exclusively to an explosion motor using gasoline—the ordinary automobile engine familiar to all. The fact has generally been ignored in this country that a type of engine, comparable in efficiency to the gasoline motor, but making use of heavy oils (as fuel oil and even crude petroleum) and suitable for power generation on a large as well as a small scale, has for many years been in successful use abroad. This is the so-called Diesel type of engine, which has its conception as far back as 1893 and “has proved to be, from a thermal standpoint, the most economical heat engine so far devised, and the one that most nearly approaches theoretical maximum efficiency.”⁴

This high-compression oil engine, as it may be termed, gains its energy from the expansion that results when oil is sprayed into a cylinder filled with compressed air and ignites under the influence of the heat of compression. The relative efficiency of this type of engine may be shown in the accompanying tabular comparison:

*The efficiency of the Diesel type of engine.*⁵

	Efficiency.
Diesel type of oil engine	4
Oil-fired steam engine (triple expansion type)	1.6
Coal-fired steam engine ⁶	1

the gasoline produced with it in the refining of crude oil. In other words, attention should not be given to the utilization of kerosene, but to the utilization of petroleum distillates containing both the gasoline and kerosene fractions of crude oil.”—E. W. Dean, Fuel for automotive apparatus, Journal of the Society of Automotive Engineers, January, 1918, p. 53.

¹ Rough approximation.

² It has been estimated for the United States that the horsepower of gasoline internal-combustion engines is over twice that of all engines driven by steam. While the latter are more continuously used, the importance of the gasoline engine in power generating is strikingly great.

³ The relatively small quantity of kerosene used in power generation need not enter the present consideration. A small portion of fuel oil is used for gas making and for other purposes than steam raising, but for most of this work coal is likewise effective.

⁴ O. P. Hood in Technical Paper 37, Bureau of Mines, 1913, p. 8.

⁵ Figures generalized from data presented in Technical Paper 37, Bureau of Mines, 1913, pp. 12–15.

⁶ For marine use the advantages of the Diesel engine over the coal-fired steam engine includes the factors of speedier bunkering, greater fuel storage, etc.

The Diesel type of engine, therefore, offers the means for greatly increasing the power-generating capacity of the petroleum yet to be produced in the United States, in itself alone having the ability to double the energy extraction from the 7 billion barrels of petroleum still under ground. But the true significance of the prospect does not appear from the general consideration. In connection with marine service has this principle its richest promise; the advantages of oil over coal for ocean shipping are well known and obvious. If America plans, as she must, on a great expansion in foreign trade and the building up of a substantial merchant marine, she would ignore her most potent point of superiority if she neglected the bearing of the Diesel engine on this matter.

It may be a source of surprise to some that the Diesel engine has been so largely neglected in this country. In this respect, a quotation from a report of the United States Bureau of Mines may be of interest:

Diesel developed his engine in the early nineties, and has since then greatly improved it and has made of it a most successful and efficient power producer. At present it is thoroughly dependable and will burn a great variety of oils * * *. Although the prime requisite in Europe seems to be economy in operation, low first cost seems to be a more important requirement in this country, and at first comparison with the steam engine the Diesel seems to be exceedingly costly. Small imperfections in mechanical construction, up to within a very recent date, seem also to have had their influence upon the non-construction of the engine in the United States. Also, although the general industrial profits within the United States are large, the very abundance of raw materials and the general extravagance in their use seem to have combined against the wide adoption of this engine, in spite of its being so highly efficient, and in spite of the fact that it has met with such success abroad. * * * The generally wasteful methods of steam raising in this country must give way to the more efficient methods of fuel utilization that now prevail in Europe, if the United States is to maintain its present position or compete with other countries in the manufacturing industries. With a more conservative use of the Nation's abundant fuel supplies and a better development of the by-product industries, there is no reason why the heavy-oil engine should not materially aid in the more efficient utilization of the fuel resources of the United States.¹

The use of gas oil, a high-grade fuel oil, in the manufacture of city gas represents a practice largely unjustifiable on the basis of resource economy. In 1915, the amount used for this purpose was about 16,000,000 barrels,² or roughly 6 per cent of the domestic petroleum production. With the exception of about one-fifth of the amount, which was employed for making oil gas in the Southwest, where coal is lacking, the bulk of the gas oil was used for carbureting or enriching the luminosity and calorific power of the various types of city gas

¹ I. C. Allen, Heavy oil as fuel for internal-combustion engines: Technical Paper 37, Bureau of Mines, 1913, pp. 9-10.

² See C. E. Leshner, Artificial gas and by-products: Mineral Resources of the United States for 1915, United States Geological Survey, p. 1051.

made from coal, in order to enable the product to meet standards imposed by municipalities—standards in part a hold over from the days when the flat-flame use of gas made luminosity a necessary feature. While, broadly speaking, the use of oil in gas manufacturing is a degradation, the practice is not only economically justifiable but actually desirable so long as the main outlet for fuel oil is for firing steam boilers, a use still more degraded with the added disadvantage of offering a smaller inducement for refining.¹

In addition to the extension of "cracking" distillation, improvements in motor design, and widespread use of the Diesel type of motor to replace the oil-fired steam engine,² an unlimited field of advance in increased value extraction opens up in connection with the building up of an oil by-products industry. But this matter has been emphasized in the preceding pages and need not be detailed again at this point. The greatness of the opportunity, however, should not be underestimated.

Development of foreign sources of supply.—In addition to the domestic production of petroleum, this country since 1911 has been drawing upon the oil fields of Mexico at an increasing rate, so that in 1917 that country supplied roughly one-tenth of our needs. The pools of Mexico, accessibly situated in the Gulf Coastal Plain, are the richest in the world and are capable of a much greater annual production than has yet been taken from them. In fact, the output, mainly under the control of British and American interests, is held in check, especially at the present time. In the Central American region in general, there are other promising oil districts, though none is developed in any way comparable to the Mexican deposits. It is not unreasonable to expect that further exploration and development will make available a reserve of oil in Mexico and Central America equal to the total remaining in the United States.³

These deposits, accordingly, offer themselves in increasing measure to supplement a waning domestic output. Their aid should be accepted, but their availability is incidental upon many uncertain factors, and obviously it would be unwise to grow into dependence upon them or permit their presence to offset action regarding the efficient utilization of our own resource. At best, these deposits and

¹ An interesting war-time development in connection with gas oil has been the installation of toluol-recovery plants in large municipal gas plants for the recovery of toluol formed from the oil in the course of gas manufacture, thus adding to the supply of toluol contributed by the by-product coke oven. It is a striking coincidence that both coal and petroleum furnish the basis for the manufacture of one of the most effective explosives known.

² Coal and hydroelectricity should also assist in replacing the oil-fired steam engine.

³ Little in the way of petroleum imports may be expected from other parts of the world; South American needs will probably more than absorb the future output of that continent.



THE SUCCESSOR TO PETROLEUM. CLIFFS OF OIL SHALE NEAR GRAND VALLEY, COLORADO.

Photograph by courtesy of Denver & Rio Grande Railroad.

especially those in Mexico, if fully available and barring international complications, would put off the period of petroleum exhaustion in the United States for only a matter of say a couple of decades; hence their presence does not change the urgency of the domestic issue. Moreover, the high-use employment of these deposits—the output is now used dominantly for fuel purposes—would be to the best interest of Great Britain, the United States, and other countries using the output, not to mention the advantage accruing to the producing Republics themselves. Indeed, it would seem, so far as such things may be determined from the outside, that Mexico would take the lead among the Republics concerned in developing a policy in regard to petroleum development that would prevent production from exceeding the demand for the high-use products, as this legitimate drain may be expected largely to exhaust the supplies within a generation or two.

On the whole, it would appear to be for the good of all concerned that the Mexican deposits should not be more wastefully exploited than those of the United States, for the world needs the full service of the aggregate supply.

DEVELOPMENT OF OIL SHALES.

Granted the utmost in the development and use of the remaining supply of petroleum, economic pressure from oil shortage will still be not far distant. Attention turns, therefore, to sources of supply other than the porous rocks of oil fields thus far exclusively exploited in this country. It is of great significance, therefore, that within the past five years geological explorations on the part of the United States Geological Survey have definitely established the existence of vast areas of black shale in Utah, Colorado, and Wyoming, much of it capable of yielding upon distillation¹ around 50 gallons of oil, 3,000 cubic feet of gas, and 17 pounds of ammonium sulphate²—the whole constituting an oil reserve aggregating many times the original supply of petroleum.³

¹ Oil shale is not supposed to contain petroleum, but upon the application of heat, it is thought, organic compounds present react to form an oil resembling petroleum from which can be obtained essentially the same products that petroleum itself yields. But this matter needs further investigation, as it is by no means certain that some oil shales, at least, do not actually contain petroleum as such. In either event, however, shale oil is practically the equivalent of petroleum.

² The occurrence and distribution of these shales, together with the results of distillation tests, are given by Dean E. Winchester, Oil Shale in Northwestern Colorado and Adjacent Areas: Bulletin 641-F, United States Geological Survey, 1917, pp. 152-155. Yields up to 90 gallons of oil, 4,294 cubic feet of gas, and 34 pounds of ammonium sulphate were obtained from certain samples. The figures cited in the text, however, represent commercial averages typical of workable areas.

³ It is estimated that the oil shales of Colorado alone underlie 1,400 square miles, with an average aggregate thickness of 53 feet, and are capable of yielding 20,000,000,000 barrels of oil, an amount approximately twice as great as the original petroleum reserve in this country, together with 300,000,000 tons of ammonium sulphate, valuable as a fertilizer, nearly 900 times the domestic consumption of that substance in 1915. The important rôle of ammonium sulphate in modern affairs is shown on the chart accompanying Bulletin 102, Part 2, of this series.

While these shales have only recently come into notice a similar resource has for many years been profitably exploited in Scotland, New South Wales, and France, where nature has been less bountiful with petroleum; while in Germany the extraction of oil from low-grade coal and other bituminous materials has become a well established undertaking.¹ The financial success and national importance of the Scottish shale-oil industry is particularly significant, as this activity offers an established technology and a basis of experience for application to the domestic oil-shale matter.² A comparison of the domestic prospects with the foreign practice, in the way of yields and values, may not be out of place.

General comparison between oil shale of Scotland and of Colorado-Utah.^a

Average yield from 1 ton oil shale.	Scotland.	Colorado-Utah.	Use.
Oil.....gallons.....	24	50	Substitute for petroleum.
Ammonium sulphate.....pounds.....	34	17-25	Fertilizer; nitrogen products.
Gas.....cubic feet.....	2,000	3,000	Fuel.
Shale residue.....pounds.....	1,600	1,500	Brickmaking; road making; possibly for extraction of potash. Undeveloped possibilities.
Cost of production.....	1910 \$2.00	1918 \$2.50-\$3.50 (?)	
Value of products.....	2.80	3.25- 3.75 (?)	
Profit, per ton of shale.....	.80	.75- .25 (?)	

^a Data generalized from various sources, including Bulletin 641-F, United States Geological Survey, 1917; Bacon and Hamor, *The American Petroleum Industry*, 1916; Hearings on oil shales before the House Committee on the Public Lands Feb. 26, 1918; personal communications from David T. Day and Russell D. George. The figures for Colorado-Utah are provisional rather than final, but are believed to be conservative.

It is apparent from this table and from the general situation in respect to petroleum that domestic oil shale may soon come into commercial importance as a producing source of oil.³ Just when will depend upon the trend of the economic situation as affecting the production of petroleum.

As a matter of fact, considerable commercial activity has already commenced looking toward the exploitation of the richer shale areas, especially in the Grand River Valley region of Colorado and near by

¹ The shale oil of Scotland has been of great service to the English Navy in the present war by supplying many oil-bearing ships with fuel, to the relief of trans-Atlantic shipments; while the German oil has proved invaluable to that country in supplementing an inadequate command of petroleum resources.

² A good description of the Scottish shale-oil industry, with many references to the literature, may be found in Bacon and Hamor, *The American petroleum industry*, 1916, pp. 807-844.

³ "These shale areas will be developed in time on as safe and sane a basis as our coal mines of to-day. When that time arrives, the remains of oil prospecting will have fled and the whole complexion of oil producing will change. It will, literally, be oil mining with steam shovels in open pits and glory holes; and, later, tunnels and adits. There will be no lack of oil products for several generations to come, but the true oil fields of to-day will probably disappear within another generation and be replaced by oil mines." Dorsey Hager, *The search for new oil fields in the United States: Engineering and Mining Journal*, Jan. 5, 1918, pp. 11-12.

in Utah. Numerous companies have been incorporated and some preliminary plants have started building. The whole matter, however, has been retarded by the uncertain status of the land laws, as well as by a general feeling of uneasiness as to the attitude of the current public-land policy toward any but a meager-scale type of development.¹ It is evident, however, on the basis of geological occurrence and experience abroad that a shale-oil industry can come into effective action only as a large-scale engineering procedure, accumulating its profit from a narrow margin made significant by the magnitude of operations.² The production of oil from shale, involving ordinary mining operations and a large distillation plant, partakes not at all of the nature of small-unit "wildcat" drilling by means of which the petroleum fields are developed.

We may pause for a moment, by way of parenthesis, to contemplate an eventual prospect of a great oil industry in the Rocky Mountains, producing two, if not more, of the four products upon which the food supply of the future turns.³ And if we recall that northwest of the shale areas lie the richest beds of phosphate rock in the world, with water power and the acid fumes of great smelters as forces of extraction, it may not be altogether unreasonable to foresee a development of a food-production industry occupying the great plains that stretch eastward from the Rocky Mountains and energized by the application of mechanical tillage and chemical fertilization upon a scale for which the past presents no parallel.⁴ Lest such a picture be regarded as too fanciful, it may be recalled that the United States Geological Survey has recently announced the discovery in Montana of phosphatic oil shales carrying a phosphoric acid content up to 15 per cent, thus combining in a single resource three of the four food essentials, gasoline, nitrogen, and phosphorus, lacking only potassium⁵—

¹ These are direct reasons, but more fundamental inhibiting factors are inherent in the economic situation as explained on page 99.

² The Scottish shale-oil industry became successful only after it boiled down to a few large, efficient companies. The budding industry in Colorado would have the advantage, if not arbitrarily hampered, of skipping this inefficient stage and at the same time of taking over a developed technology shorn of its obsolescent features. It is estimated that a plant in Colorado capable of handling 1,000 tons of shale and clay would cost between \$2,000,000 and \$3,000,000, but a unit of this size would be small as such things go.

³ Reference is had, of course, to tractor fuel and nitrogen (ammonium sulphate), the other two being potassium and phosphorus.

⁴ The only element definitely lacking is potassium, and the prospect of that essential is more promising in the general western region than elsewhere in the United States. In connection with ammonia recovery in the by-product coke oven, suggestive experiments have been carried on looking to the absorption of the ammonia by means of phosphoric acid instead of by the customary sulphuric acid; the bearing of such a process, if successful, upon the shale-oil matter is significant.

⁵ C. F. Bowen, Phosphatic oil shales near Dell and Dillon, Beaverhead County, Mont.: Bulletin 661-I, United States Geological Survey, 1918. This work opens up promising possibilities in respect to the occurrence of phosphoric acid in some of the oil shales elsewhere in the Rocky Mountain region, and suggests also a new field for petroleum exploration in those places where such shales occur under geological conditions which may have given rise to a natural process of distillation.

and even potassium is reported to be present in small amount in the Colorado shale.

While the most conspicuous oil-shale areas recorded in this country are in Colorado, Utah, and Wyoming, with the most immediate interest centering around those of Colorado and Utah, other oil shales are found in Nevada,¹ California, Montana, Arizona, Oregon and in many of the central and eastern States—aggregating an immense area and representing a potential source of oil sufficient to supply this country hundreds of years.² Of course it is evident that much of this shale has a prospective interest merely;³ but there are certain beds overlying shallow coal seams, which offer themselves as productive possibilities even under present conditions, as the shale is a waste product to be removed anyhow in connection with the open-cut mining methods coming into vogue for close-to-the-surface coal seams. Thus, it is not impossible that coal-mining in the central and eastern part of the country, within a very few years, may support a budding shale-oil production, coming in, along with the output of the western shale-oil industry, to offset the decline in petroleum yield.⁴ Still other possibilities open up in connection with the production of oil, gas, and by-products from cannel coals;⁵ the whole matter in this wise passing over into the realm of by-product coal utilization, whose possibilities have been developed in earlier pages of this paper. It becomes apparent, then, that coal and oil are not merely rivals, but are brothers in a common purpose—the production of energy and chemical products.

The presence in this country of extensive deposits of oil shale removes the danger of early physical exhaustion in respect to oil, but it does not necessarily insure a deferment of the period of economic exhaustion which is being prematurely rushed into the present by the

¹ Experimental plants are being erected in both California and Nevada.

² The eastern shale areas are described by George H. Ashley (Oil resources of black shales of the eastern United States: Bulletin 641-L, United States Geological Survey, 1917), who provisionally estimates that southwest Indiana alone is underlain by shale sufficient to produce 100,000,000,000 barrels of oil, over fourteen times the present petroleum reserve.

³ Ashley estimates that under present conditions a barrel of crude oil produced from eastern shale of average quality will cost about \$4.20, little more than such an oil would be worth at present, barring by-product possibilities not possessed by its rival, petroleum.

⁴ This whole matter of by-product development is of profound significance to the future of the Nation, to a degree, indeed, difficult of appreciation by anyone who has not focussed on the germs contained in the prospect. The possibilities of a shale-oil industry enmeshed with coal production affords promise to the already overdue arrival of a significant output of coal-pyrite, a product wasted in coal production, but needed for the manufacture of sulphuric acid. (See J. E. Pogue, Recovery of sulphur in Illinois coals: Met. and Chem. Eng., November, 1917, pp. 584-585.) That sulphuric acid is needed both in the recovery of ammonia from oil shale and in the refining of the shale oil itself is merely one example of how thoroughly by-product activities dovetail.

⁵ See George H. Ashley, Cannel coals of the United States, Bulletin 659, United States Geological Survey, 1918.

current wasteful use of the limited petroleum resource. For that purpose an effective and adequate development of oil shale must start somewhat in advance of the wave of need that would normally dictate the launching of this leaner resource. That wave is already definitely in sight; the question is merely whether we will wait until it breaks or now prepare for the force of the impact so as to ease it off. It need scarcely be emphasized that any action directed toward the tying up of the oil-shale reserves, pending a determination of policy regarding their disposition, would be disastrous. The American public is probably sufficiently aware of the irretrievable harm wrought by this course of action in regard to certain other less vital resources, under the influence of the wave of so-called conservation that swept over the country a decade ago, to countenance a repetition of such temporizing action.

DEVELOPMENT OF SUBSTITUTES.

Even with the most efficient use of the remaining supply of petroleum, and an appropriate development of shale oil in prospect, the petroleum situation can be additionally improved by a progressive utilization of substitutes for gasoline and fuel oil, so as to give better economic balance by relieving the products upon which fall the heaviest demands. Two substances, benzol and alcohol, are suitable for helping gasoline, and offer the advantage of a record of successful use in motor engines in Europe prior to the war, and of a marked extension of utilization there under the rigorous conditions of the present conflict, while coal and hydroelectricity may be brought to the aid of fuel oil.¹

Benzol is a light liquid, somewhat similar to gasoline in character, obtained at present from the by-product coke oven. The production of benzol in the United States is at present small, owing to the fact that only about a twelfth of the bituminous coal mined is treated for the recovery of by-products. The full utilization of benzol therefore must go hand in hand with the development of methods, as outlined on pages 7-28 of this paper, whereby coal will be made to yield a complete measure of usefulness; indeed, the proper utilization of coal demands a market for benzol as a motor fuel, while the proper shaping of the petroleum resource permits and needs the coming in of benzol as an alternate for gasoline. Thus once more appears an example of how closely the various elements of the fuel situation are connected.

¹ Recent work on castor oil production gives some indication that this organic product may come to be a significant source of motor fuel.

The total capacity toward benzol production possessed by the coal annually produced in the United States is upward of 1,000,000,000 gallons,¹ which in terms of gasoline represents about one-half of our annual consumption of the latter. Compared with gasoline, benzol yields better efficiency in the internal combustion engine, but presents a slight disadvantage in respect to use in cold weather. It may be used successfully in the ordinary gasoline motor by admitting a little more air than is customary for gasoline, or by mixing with gasoline.

Alcohol is familiar to everyone and as a fuel offers the advantage that it can be made from organic products which reproduce themselves from year to year and include vast quantities of materials that ordinarily go to waste.² Unlike the mineral fuels, therefore, it does not constitute a drain upon a reserve fixed in quantity. The difference in effectiveness for motor use between alcohol and gasoline is slight; for whereas gasoline yields a trifle more power to the gallon and is easier "starting from the cold," alcohol is safer, cleaner, and more pleasant as to exhaust odors. The capacity of this country in respect to alcohol production can not be closely stated, but if the output of alcoholic beverages is any criterion,³ existing distilleries upon conversion could at once produce fuel alcohol to the extent of millions of gallons, whereas the substitution of waste products for grain would effect a great economy over the cost of denatured alcohol as made at present. If, in addition, the perplexing legal difficulties that now hedge in such a development could be circumvented, the use of individual manufactories on farms could readily furnish a perpetual supply of motor fuel at little cost, where a cheap motor fuel would have its most far-reaching social effect by tending to lower the cost of food.⁴

Artificial gas made from coal offers a convenient substitute for gasoline in certain types of stationary internal-combustion engines, while the suction producer plant, with its adaptability to the em-

¹ On the basis of a yield of 2 gallons to the ton of coal.

² Alcohol can be made from starches, sugars, wood waste, sulphite liquors from paper manufacture, peat, cornstalks, etc. Its cost in Germany several years ago was as low as 25 cents a gallon; in England, 33 cents a gallon—prices comparing favorably with the present cost of gasoline in the United States. Rittman estimates on a prewar basis that alcohol would become a commercial fuel in the United States when gasoline exceeded 35 cents a gallon. (*Journ. Ind. and Eng. Chem.*, May, 1917, pp. 528-530.)

³ It is worthy of note that the consumption of alcoholic beverages and of gasoline during 1916 in the United States was approximately equal; each close to 2,000,000,000 gallons, equivalent to a per capita consumption of about 20 gallons.

⁴ Tropical countries will find fuel alcohol very economical because of the practically unlimited supply of raw material available for its manufacture and the decided advantages of its use over gasoline in very hot climates. The Tropics, with their rank growth of vegetation, offer the most available energy source in sight, after coal, water power, and oil; and hence may eventually take on a much greater importance in this respect than they now possess in all other respects. Their capacity for producing fuel alcohol and food offer an interesting prospect to resource pessimists. The extraction of castor oil from the castor bean and stalk also presents a promising prospect, as several barrels of oil can be obtained per acre and the oil can be made into motor fuel and lubricants.

ployment of lignite and other low-grade fuels, offers a wide field of usefulness to the partial relief of gasoline, especially in motor boats. Artificial gas may even become suitable for automobile use through the development of appropriate methods of compression or even liquification, so as to enable its storage in small compass. Even without such treatment, but under the stress of gasoline shortage, artificial gas has met with successful motor use in London during the present war; motor busses and other conveyance carrying large canvas containers filled with gas having now become commonplace objects in England.

Fuel oil¹ has come into extensive use in the United States, especially in the far West, as a substitute for coal. It is more convenient than coal and is therefore adopted by industries wherever its price is low enough to permit its use. Its employment in this way can not be sustained, in view of the slowing rate of petroleum production and the counter demand that will come in increasing measure from the further development of "cracking" practice in refining and from the wider adoption of the Diesel type of internal combustion engine. It will soon be necessary, therefore, in any event, to bring coal and hydroelectric power to the aid of a growing number of those activities now dependent upon oil fuel; and the whole matter may be facilitated, to the benefit of the petroleum resource in particular, by constructive action in respect to coal and water-power,² so as to make their service in this respect more immediately available.

THE SOLUTION.

There are three outstanding features in the petroleum situation of unescapable significance. These are: the strictly limited size and decreasing availability of the petroleum reserve, the growing importance of certain of the products made from petroleum, and the tremendous waste involved in the current method of bringing petroleum into use.³ The first two circumstances, of course, make the last important. If there were plenty of petroleum, waste in its use would not matter. Or if petroleum were of no great value, merely a luxury, neither waste nor limited quantity would make any great difference. Even if the supply were limited, but sufficient say for 50 years, it might be difficult to summon any interest at this busy moment to the issue. But petroleum is a basic necessity, as much so as wheat or wool, and its exhaustion is already beginning to be felt. The matter, then, can not be safely deferred.

¹ Including crude petroleum.

² See Parts 1 and 3.

³ It would be flattering to present usage to estimate that the resource is made to yield over 10 per cent of its latent value, considering the proportion left underground, lost in extraction, and inadequately used.

FUNDAMENTAL CAUSES OF WASTE.

If the petroleum supply is weakening, it is obviously desirable to examine the portion that is wasted. We have previously observed in some detail what these wastes are and where they take place—the oil left underground when the field is abandoned, the gas permitted to escape into the air or into barren formations, the destructive infiltration of water into the oil sands, the rapid production with demoralization of prices if the pool is large, the losses involved in storing the oil until it can be transported to market, the drilling of unnecessary wells, the inferior use to which much of the oil is put. These matters, of course, are well-known and notorious. But they are manifestations merely. We must look deeper for the root causes that give rise to these wastes.

In the production of other raw materials there are no such conspicuous wastes as characterize the production of petroleum.¹ There would appear to be, then, some fundamental factor peculiar to petroleum and conditioning the wasteful procedure common to its exploitation. This factor is not far to seek; it lies in the fact that petroleum is a migratory mineral² and moves underground in the direction of decreased pressure. This factor, activated by unrestricted competition in production as commonly practiced in the United States, is the fundamental cause of the wastes so preponderant with petroleum. Because petroleum is not fixed in position and much of the production, especially in young fields, is won through the efforts of small operators occupying small tracts, usually leased, there ensues a competitive scramble on the part of each operator to reach oil as quickly as possible and produce it as rapidly as possible. This means a ruthless sacrifice of all but the easy-to-get values. Even if an operator desires to defer production or restrain his output, as a rule he can not do so because a rival operator with a neighboring well will suck from under his feet the oil which his lack of action relinquishes. So long as the ownership of oil is determined by vertical boundaries, arbitrarily dividing a geologic unit or reservoir into many portions, just so long will there be hurried production with all its train of losses.³ (See figs. 12 and 13.)

¹ With which is included natural gas. The wastes in the production of coal are also conspicuous, but less than in the case of petroleum. It is a striking fact that the greatest wastefulness characterizes the exploitation of the energy resources.

² Natural gas and water also display this property; and in both there is waste. In the case of water, however, the waste is of slight consequence, since the supply is unlimited.

³ Max W. Ball presents the matter very effectively in the following quotation (Adequate acreage and oil conservation, Proc. Amer. Min. Congr. November, 1916, pp. 322-333):

"There is the root of the whole trouble—the small holding. Let us go back over the history of the field.

"We saw that as soon as the field was discovered it was leased up in small tracts. Then we saw the Smiths, the Browns, the Joneses, and the Standard Oil drilling for dear life, each trying to get the oil from under his little tract and a bit of the other

The headlong production of oil is greatly facilitated by further circumstances. The gambling character of wildcat drilling in itself leads to the desire for quick returns, with little regard to the niceties of engineering efficiency. Then, the automatic character of production, once the oil is reached, attaches small cost to the actual production—not infrequently, in fact, it costs more to retard the output than to produce at maximum speed. Thus an incentive is lacking for exercising care with a product gained easily and oft-times lavishly. There is, also, practically an unlimited demand for cheap petroleum for inferior uses, affording a convenient outlet for hasty production and tending to support the grossest overproduction with at least a modicum of profit.

Accordingly, because the cost of production is slight, wastes in production are of little consequence to the producer; while, due to the competitive race for extraction, production is unrestrained. Thus oil is produced with no adjustment to the legitimate (that is, high use) demand, which gives a surplus of cheap oil that takes advantage of and encourages the ever-present latent demand for oil fuel. Indeed, certain oil companies, usually small or newcomers in the oil business, find their only opportunity in the direction of encouraging the use of oil fuel; hence there is a strong pressure of advertising propaganda in this direction.¹

This may appear to be an exaggerated account of petroleum production.² But such are the motives and conditions that prompt the production of the major part of the output of the United States and

fellow's before the other fellow could get it. Why? Because each tract was so small it could be drained by wells on the surrounding tracts.

"We saw that the race was so keen that wells were improperly drilled, that gas was allowed to waste into the air or dissipate itself through barren formations, that water was allowed to enter the oil sands, and that great quantities of oil were left underground, never to be recovered. Why? Because the small holding forced each man to race with his neighbor.

"We saw the entire flush production of the field thrown on the market at once, demoralizing market prices, forcing the premature abandonment of wells in other fields, resulting in the burning of unrefined crude and the waste of the more valuable products. We saw the maximum production of the field go into storage, where the losses from evaporation and fire were enormous, and where the cost of the oil was nearly doubled. What caused these things? The fact that every holder of a small lease must drill it up as soon as possible.

"Lastly, we saw the cost of production more than 300 per cent what it should have been. And what was the reason? That every man must drill his lines as fast as might be, and must completely drill up his land at the earliest moment. Why? Because the oil under his small holding could be taken from him by wells on surrounding tracts.

"Ignorance there may be, carelessness there undoubtedly is, but back of ignorance, of carelessness, of reckless, headlong methods, is the real cause—the fact that the average holding is so small that speed is the owner's sole protection. Let him be careful if he can; let him be economical if he can find a way; but careful or careless, reckless or conservative, he must be speedy if he would survive. The small holding is his master."

¹ The fact that certain oils contain naturally a relatively small proportion of the higher-use products, such as gasoline, is beside the point. If the Appalachian field had yielded such an oil, methods of refining would have turned it into the higher channels of use. See the discussion on "cracking" distillation, page 18.

² Possibly because the picture is painted in terms of homely, everyday experience; but the issue is too important to be trusted to the cold atmosphere of technical expression.

hence dominate the situation. With increasing scope of organization in production, of course, these conditions tend to modify. With broadly integrated operations, production may escape entirely the influence of the factors noted. But, by and large, the situation in the United States is this: it costs a good deal to reach oil,¹ but little or nothing to produce it. When reached, the oil must be produced as rapidly as possible, else some one else will get it. There is an unlimited

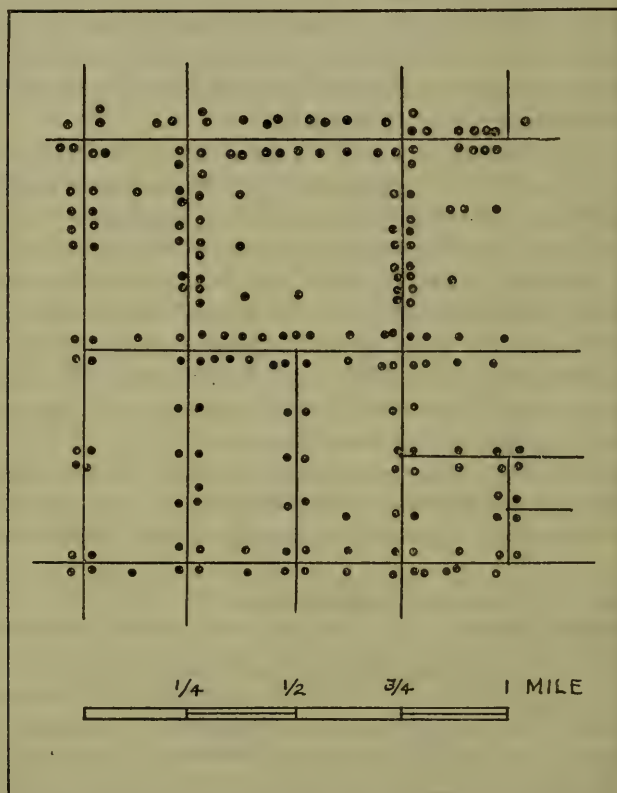


FIG. 12.—DIAGRAM SHOWING THE RELATION OF OIL WELLS TO PROPERTY LINES IN A TYPICAL PORTION OF THE MOST PRODUCTIVE LIGHT-OIL FIELD IN THE WORLD. NOTE THE SMALL HOLDINGS, EXCESSIVE NUMBER OF WELLS, AND THE TENDENCY OF WELLS TO OCCUR IN PAIRS ON THE OPPOSITE SIDES OF PROPERTY LINES. THIS DIAGRAM EPITOMIZES THE FUNDAMENTAL CAUSE OF PETROLEUM WASTE IN THE UNITED STATES. DATA FROM MAP BY CARL H. BEAL, GEOLOGIC STRUCTURE IN THE CUSHING OIL AND GAS FIELD, OKLAHOMA, BULLETIN 658, U. S. GEOLOGICAL SURVEY, 1917, PLATE 4.

demand for the crude product, with profit in such sale. In brief, the free operation of the law of supply and demand under continuation of small-unit competition in oil production is forcing the sacrifice of the greater part of our most essential and most limited resource.

If so much be granted—and whatever the difference of opinion as to cause, the limited size and wasteful exploitation of the resource

¹ Much of this cost, under present conditions, is borne by unsuccessful prospectors.

are incontestable—the question arises as to what may be done with the situation. Four lines of action, in the way of national policy, present themselves for consideration.

THE LAISSEZ-FAIRE POLICY.

Industrial development in this country has been intrusted to the automatic control exerted by natural law—the law of supply and demand—working under free competition. Such interference with the natural course of industrial development as national policy has dictated has been in the direction of maintaining conditions of free competition against an integrative or monopolistic tendency. This policy of leaving industrial growth to the stimulus and retardation of attendant circumstances may be termed a policy of noninterference or laissez-faire. Such a policy apparently developed on the assump-

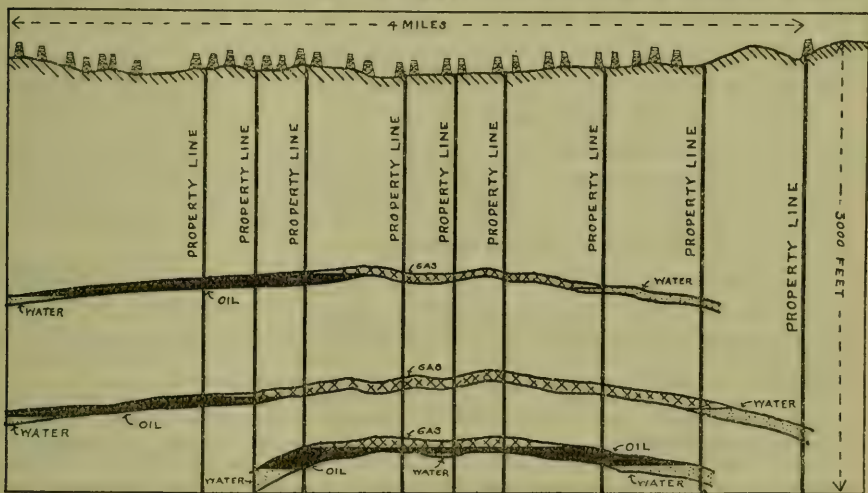


FIG. 13.—DIAGRAM SHOWING THE TYPICAL UNDERGROUND OCCURRENCE OF OIL, GAS, AND WATER, AND THE CUSTOMARY DISCORDANT RELATIONS BETWEEN PROPERTY LINES AND GEOLOGIC OCCURRENCE. THE MIGRATORY CHARACTER OF OIL RENDERS THIS TYPE OF DEVELOPMENT UNSOUND AS LEADING TO A RACING AND WASTEFUL EXTRACTION OF THE OIL. THIS DIAGRAM EXPRESSES THE UNDERGROUND RELATIONS OF THE SURFACE CONDITIONS DEPICTED BY FIGURE 12. DATA FROM CARL H. BEAL, GEOLOGIC STRUCTURE IN THE CUSHING OIL AND GAS FIELD, OKLAHOMA, BULLETIN 658, U. S. GEOLOGICAL SURVEY, 1917, FIGURE 3 AND PLATE 4.

tion that all industrial activities react alike and favorably to this treatment. If, however, at any later time it becomes clearly apparent that in a given field matters are working out disadvantageously under a sweeping-rule policy, it is a fit subject for inquiry whether a point of departure is not there afforded and justified in respect to a change in plan, so as to bring the activity into a more profitable and congenial atmosphere. It would appear that, so far as petroleum is concerned, a continuation of the policy of laissez-faire will perpetuate the circumstances which are forcing a premature exhaustion of a limited and vital resource.

The policy of *laissez-faire* is so firmly established and so apparently effective in the general run of industrial growth that many hesitate to abandon it in specific instances, however urgent the need in point. But at least the consequences of allegiance in such instances should be visualized. In the case of petroleum, under continued *laissez-faire*, we may expect to be confronted, some 15 or 20 years hence, with the discomfiting realization that our domestic resource has been impoverished, a dependence upon a foreign country has developed, and the opportunity for betterment has passed—wasted. This is a simple matter of arithmetic, not an adventure in prophecy.¹

THE ADVISORY POLICY.

In an earlier part of this paper, the recent developments in petroleum technology have been reviewed in a broad way, and it appeared that considerably more technological knowledge has been accumulating than has found a way into action. Much of this technical advance has been affected by researches and investigations in petroleum technology on the part of governmental bureaus, notably the Bureau of Mines² and the Geological Survey,³ and in this way the Government has assumed an advisory capacity in respect to the development of the petroleum resource. Creditable progress in increasing resource efficiency has thus been attained—a heavy return, indeed, upon the small investment made in this direction.

Such work, advisory to industry, is of great importance and should be encouraged by adequate support.⁴ But with petroleum, at least, technological advice and information alone are impotent to get at the

¹ Writes M. L. Requa, in speaking of the wasteful use of coal and oil:

"Our very prosperity makes us careless of the future; we feast and revel while the handwriting blazes on the wall in letters of fire, and we do not pay it even the cold compliment of a passing glance. As a Nation, we are wasteful, apathetic, and forgetful. We waste our natural resources with shameful prodigality; we are apathetic of the future, and we forget that our reserves of natural wealth are by no means inexhaustible. * * * We vaguely realize, if we condescend to think about it at all, that when such a time shall have arrived, in some distant generation, that centers of manufacturing must change and things generally undergo a radical realignment. And then we remember that the problem is, after all, one for distant posterity, and that posterity should shift for itself and we drowsily mutter '*laissez-faire*' and forget the future in our supreme self-satisfaction in the present. * * * Those of us who believe that posterity must settle these problems of heat, light, and power are living in a fool's paradise, and must inevitably awaken within the next few years to face, subdued and chastened, the real truth." (Exhaustion of the petroleum resources of the United States, Senate Document No. 363, 64th Congress, 1st session, 1916.) The speed with which this prediction has come true has perhaps amazed even its sponsor.

² The United States Bureau of Mines was not established until 1910, but since that time its Petroleum Division has notably advanced the field of petroleum technology, as may be readily gathered from a survey of the publications of this bureau.

³ The United States Geological Survey has for several decades been engaged in the geological study of the oil fields of the country and publishes an annual statistical record of the domestic output of petroleum. The mapping of the underground structures, as embodied in numerous bulletins, has furnished a wealth of information of immediate practical value in connection with the development of new territory and the location of successful wells; while the inventory of the petroleum reserve made by the Survey represents an invaluable contribution to resource knowledge.

⁴ The United States only devotes some three or four million dollars a year to investigational work bearing on the mineral industries in their entirety—a strikingly low figure, considering the magnitude of the field.

roots of the trouble. So long as economic conditions encourage waste in petroleum exploitation, no amount of technical and scientific knowledge will more than scratch the surface of the matter. The advisory policy, therefore, is an incomplete policy—good so far as it goes, but it doesn't go far enough.¹

THE AUTOCRATIC POLICY.

Secretary of the Interior Lane, in his annual report for 1915, says in regard to petroleum: "An absolute government would prohibit a barrel of it being used for fuel before every drop of kerosene, gasoline, and other invaluable constituents have been taken from it."² An autocratic government by fiat could probably eliminate waste from petroleum exploitation by enforcing arbitrary laws to this end. But we do not have an autocratic government and, moreover, the type is in the course of passing into universal discredit. But even democratic governments sometimes deal with such problems in a harsh or rather arbitrary manner; in point of fact, it is a somewhat widespread feeling that wastes and economic maladjustments can be legislated out of existence by wisely drawn laws, even in a republic. Fiat methods, however, apart from being inconsistent with our professed principles of government so as not to merit wide approval, may also be seen, both in the light of past experience and of common sense, to offer a prospect only of harm. Thus, to give extreme suppositions, a law demanding increased recovery from wells would result in a lowered production, with an industrial mix-up; a requirement that oil be no longer used for steam-raising would cause the Southwest to starve to death; a call for efficient drilling would throw chaos into oil production. The legitimate and illegitimate strands have become so closely interwoven that it is now impossible to improve the pattern by plucking out the economically inartistic threads.

THE CONSTRUCTIVE ECONOMIC POLICY.

This country has applied the laissez-faire and advisory³ policies to petroleum without adequate betterment of the situation so far as wastes are concerned. It has even tried certain forms of legalistic or dictatorial force in the way of interjecting competition into phases of the matter already integrated⁴ or by nature noncompetitive,⁵ but

¹ An advisory policy is really a part of a constructive economic policy.

² An absolute government, indeed, would presumably go further and require the fuel residuum to be used in the Diesel type of internal-combustion engine instead of under steam boilers.

³ No intent to belittle the advisory policy is in mind, but that policy is limited in the good it can accomplish by circumstances over which it, per se, has no control.

⁴ The operation of the Sherman antitrust laws in disintegrating the Standard Oil Co. into a number of subsidiary companies is an example.

⁵ Illustrated in the case of the Walsh bill (S. 2812, 1918), opening public oil lands to development in 160-acre tracts. The United States, through the Geological Survey, has spent millions of dollars in learning and proving that oil does not occur in 160-acre tracts, yet it tries to force oil to so occur by fiat, or, at least, ignores legally the fact that oil is migratory.

with no beneficent effect upon the resource as a whole. Neither technology nor law can meet the issue unaided—and no one wants the autocratic method, good or bad. Is there no way, then, whereby this country can administer its petroleum resource without waste, yet with fairness to all interests? Must we admit that to gain a legitimate service from petroleum we must sacrifice nine-tenths of the resource? Such a necessity is scarcely conceivable, yet it seems to exist. Such a necessity, indeed, does exist, so long as the petroleum resource is left subject to the untrammelled operation of the law of supply and demand under conditions of unrestricted competition in production.

The betterment of the petroleum situation, in the last analysis, depends upon the recognition of a principle and the incorporation of that principle in a broad national policy bearing on all industrial matters—a policy which we may term a constructive economic policy. The principle is this: That natural economic law is not invariably beneficial in its action, however advantageous in the majority of instances; that it requires surveillance and, in those cases where it fails, constructive help. This principle is perhaps most strikingly exemplified in petroleum, where the automatic control exerted by natural law has unmistakably demonstrated incompetence, but it is also true of a sufficient number of activities to have general significance. A constructive economic policy is desirable, then, not on the score of petroleum alone, but in behalf of the industrial development of the country at large. It would be scarcely possible to create machinery to handle the petroleum problem effectively as a single matter; petroleum is too closely enmeshed with the whole industrial life of the country thus to be singled out.¹

The general need for a constructive economic policy can not be gone into in detail here. Its general desirability and scope will

¹ The need for a constructive economic policy is especially apparent in the production and utilization of mineral raw materials. If the reader could view, in rapid succession, the curves showing the increasing consumption of the various mineral resources and at the same time realize that the reserves of these resources (of the richness now worked) are strictly limited, he would be strongly impressed with the fact that sooner or later the world must make full use of the raw materials which are now so incompletely utilized.

A widespread and general feeling in regard to such matters seems to be, so far as may be gathered from everyday experience, that a constructive policy in regard to resource efficiency would prove destructive from a human or personal standpoint, and therefore resource waste is justified on the basis of its moral safety. This view seems also to have gained ground from the more or less current feeling that the moral obliquity of Germany is in part a product of her industrial organization, which has naturally lent no popularity to the idea. But these considerations are believed to be beside the point; mineral resources (as apart from organic resources) are limited in quantity, are being used up with extraordinary rapidity, and the time will come for each limited resource when waste can no longer be tolerated. No matter the justification of compromise on other grounds, sheer physical necessity will dictate full utilization. That time is almost here for petroleum, just as it is temporarily here for wheat. Individualistic proclivities must give way before resource exhaustion. But, on the other hand, it may be questioned, purely on a moral basis, if wasteful utilization can be on as high a plane as full utilization.

probably become clearer in the course of the ensuing discussion on its applicability to the petroleum problem. In this respect, a constructive economic policy would come into effective play by seeking out those aspects of the petroleum industry in which natural economic law, as it now operates, has not led to sound development; it would then study those maladjustments and smooth them out by appropriate measures so as to bring the entire resource activity into effective operation. Sufficient, perhaps, has already been set forth in this paper to make clear that the glaring flaws lie in the realm of production and arise from the fact that the supply, due to various factors, is out of adjustment with the demand. If these degrading factors are permanently set aside, then the whole matter may be intrusted again, and this time safely, to the automatic regulation of natural economic law.

Lest a constructive economic policy be regarded as an unduly radical step, involving elements of greater danger than of prospective advantage, we may examine more specifically what its course of action would involve.¹ The main lines of advance are clearly marked out. They indicate that a constructive economic policy would discourage unrestricted competition in production, provide for a tapering use of oil for steam-raising, insure the development of petroleum by-products, pave the way for the sound establishment of a shale-oil industry, and stimulate the production of benzol and alcohol as motor fuel.

Discouragement of unrestricted competition in production.—We have seen that the geological occurrence of oil leads to lavish production, a tendency that is given extravagant license by the small-unit competitive mining operations prevailing in this country. Hence there has long been an overproduction of oil in respect to the real needs of the country, with frequent spurts of gross overproduction. In these circumstances lie the major causes of waste and inferior utilization all along the line. By some means production must be brought under the control of legitimate demand. A constructive policy, recognizing this desirability, will encourage a type of development that will hold petroleum in the ground until it is actually needed for high uses.

The first step toward this end would logically be to disfavor small holdings. In the case of the public lands, this could be accomplished by appropriate legislation permitting the patent or lease of adequate acreage.²

In the case of private oil lands, either developed or in prospect, a constructive policy will favor and facilitate integration, at least up

¹ Any action that harms either established industry or the public interest is not constructive. Such may be the criterion through the use of which a constructive economic policy may safely be applied.

² Bills now pending in Congress (H. R. 3232 and S. 2812) scarcely go far enough in this direction.

to the point where each geological unit is occupied by a single producing activity. Anything short of this leads to competitive racing for extraction, the most potent single impetus toward wastefulness. As integration is a natural tendency, perhaps no artificial stimulus would be necessary to attain an appropriate result, other than a policy advertising its desirability and perhaps obtaining the passage of standardized leasing laws forbidding grants of inadequate holdings. Petroleum mining can not be administered so as to give every comer a chance; that is inconsistent with the public interest because of the peculiar occurrence of petroleum; so much of individual right must succumb to the common good.¹

Whether production should become integrated in further degree, or come more fully under the ownership control of the handling activities, transportation and refining, need not be settled here. Certainly, however, for good effect production must be controlled by demand working through refineries; production, then, can not be independent in fact. Hence integration in this respect is unavoidably present, whether materialized in formal arrangements or not.

The common objection that an integrative tendency must be combated as leading to monopoly need not detain the argument. A constructive economic policy may be expected to find means whereby it can protect the public from the undue exercise of the power inherent in large integrated activities. Indeed, that safeguard has already of late developed to considerable measure through the simple expedient of publicity of operations. Neither constructive policy nor integrated industrial operations will soon again underestimate the power of enlightened public opinion.²

¹ The bearing of this matter on the public lands, although it is equally applicable to developments in general, is well expressed by Max W. Ball in testimony on the public lands given before the House committee on Feb. 8, 1918, as follows:

"It seems to me * * * that there are two fundamental theories as to the disposition of public lands * * *. The first of these is to so dispose of the public lands that the largest number of individuals will be able to make a living from them, make a profit from them, or in some way enjoy individually the benefits of the public domain * * *. Suppose we call that the 'individual-bounty' theory, which, I think, describes it fairly well * * *. The other theory is to so dispose of the public lands that their products will be available to the public with the minimum of waste and at minimum cost. Suppose we call that the 'consuming-public' theory, for want of a better name. Possibly as good an example as we have of that theory is the mineral-land laws, under which we have had such marvelous mineral development in this country in the last two or three generations. Those laws, you will remember, although they provide a limited area for each claim, make no restrictions as to the number of claims that may be operated together and therefore permit small unit operations or large unit operations as may be necessary to get the mineral products to the public at the lowest cost * * *."

² It may be presumed that the large units engaged in the handling of petroleum would have gone more fully into organized productions had not they faced a public opinion suspicious of any such trend toward what would popularly be termed "monopoly." As these activities could command, anyhow, all the oil they wished without directly controlling production, there was no pressing incentive to go into any branch of the activity that might invite further destructive attention from public opinion. Both the public and the petroleum industry have been the losers in this period, now passing, of mutual distrust.

The elimination of excessive competition in oil production, that is to say, of competition within the geological unit or reservoir, will go far toward placing petroleum on the same footing with other mineral products. It will lessen the gambling aspect of oil-field exploration by bringing a greater measure of engineering practice to bear on the search for oil.¹ It will strike to the roots of wasteful production and overproduction by enabling the producer to gain greater profit in holding the oil underground until needed and then producing it according to the best current technique than by rushing headlong into hasty production as is necessary under present circumstances. It will create conditions of supply that will cater indifferently to inferior uses, to the sustained benefit of all activities actually dependent upon the distinctive character of petroleum products. In a word, this simple expedient will prevent the migratory character of petroleum from working at severe cross-purposes, as it now does, with the best interests of the petroleum industry and the public.

Tapering use of oil as steam-raising fuel.—While better rounded integration in the production of petroleum will find physical wastes unprofitable and lose interest in supplying low-use demands, a constructive economic policy will also clear the path of certain obstacles now retarding an efficient utilization of petroleum. These obstacles are chiefly two: The large amount of fuel oil thrown on the market as a necessary product of refining, which must find an outlet; and the industrial dependency upon oil-developed steam power, strongly marked in certain parts of the country lacking in coal. A wise policy will turn the use of fuel oil into higher channels and narrow the necessity for employing the oil-fired steam engine.

In respect to fuel oil, we have already seen that "cracking" distillation can turn it in part into gasoline, while without change fuel oil may be used efficiently in the Diesel type of engine. Here are the means, then, for escaping the steam-boiler use of oil. "Cracking" may be expected to come into practice as needed, but its progress would be facilitated by extended research on a commercial scale in keeping with the true importance of this matter.² The Diesel engine has been scarcely used in the United States; its introduction on a broad scale may be facilitated by a campaign of educational information, by the encouragement of manufacturing plants, and particularly by favorable consideration for adoption in connection with the Navy and merchant marine of this country.³

¹ A substantial gain from this will lie in the field of investments in respect to lowering the losses now so abundant in connection with fake and unsubstantial oil companies.

² Such work is being done by the Bureau of Mines, but with financial support scarcely in keeping with the potential importance of the experiments.

³ The British ministry of reconstruction has a provisional committee for the internal-combustion engine industry which, presumably, will press this matter for Great Britain.

The disuse of the oil-fired steam engine may be encouraged and permitted through the proper development of other energy resources, such as coal and water power, as suggested in Parts 1 and 3 of this paper.¹ The extent of the dependency of the country upon oil-fired steam power is amazing in view of the slimness of the resource; changes in this respect, in any event, must be forced within a very few years. The lack of a constructive economic policy has permitted this country to run into its present unsound condition in respect to fuel oil; the sooner the enlarging use be turned into a narrowing use, the better.¹

The fuel-oil problem carries peculiar significance to the Southwest, for most of the far western railroads and industries and much of the Pacific coast shipping are utterly dependent upon fuel oil for energy. Indeed, the fuel situation in the Western States and on the Pacific is fundamentally different from that in other parts of the United States. Because of the prolific oil fields of California, which came into play at the beginning of an era of great industrial growth and the distance of the Pacific region from important coal fields, petroleum in that section is both coal and oil, so to speak. It can not long play the double rôle; in fact, even now, the situation is badly strained. Accordingly, the matter there is already an issue of grave importance. The far West must either turn to coal, hauling much of it long distances, or else develop cheap electric energy from the streams of the Sierra and Coast ranges. It so happens, however, that over one-third of the available water power of the country is to be found in the States of California, Oregon, and Washington, ready to release oil from its crudest use as soon as an adequate policy of national water-power administration comes into play.²

¹ The reduced utilization of fuel oil that would come from the wider employment of the Diesel type of engine and the substitution of coal and hydroelectric power in appropriate degree would practically eliminate the low-use demand for petroleum products, permitting the production capacity of the country to meet the legitimate demand for some years to come.

² The California State Council of Defense (Report of the committee on petroleum, July 7, 1917, p. 153) estimates that fuel oil in San Francisco would have to advance from \$1.45 a barrel, the 1917 cost, to \$2.66 a barrel—that is to say, double—before it would become as costly as coal at \$8 a ton. "It is evident," this report goes on to say, "that at present relative prices of fuel oil and coal in California, few consumers of fuel oil will voluntarily give up its use and revert to coal * * *." This report also reviews the water-power situation (pp. 169-172) and states that the minimum potential water-power resources of California, Oregon, Washington, Nevada, and Arizona is 12,619,000 horsepower, 45 per cent of the water-power resources of the entire country. Of these potential resources only about one-tenth is now developed, the equivalent in fuel oil of 19,000,000 barrels annually, while approximately one-third "can be developed as required at an average investment cost which will permit of successful and profitable operation under present conditions of the western power market." The undeveloped but practicable water-power resources of this section, then, are capable of replacing over 50,000,000 barrels of fuel oil annually, or approximately two-thirds of the present consumption of fuel oil in this section. Hydroelectricity, the Diesel engine, and a slight use of coal are capable, if properly directed, of solving the fuel problem of the far West.

Encouragement of multiple-product¹ (by-product) development.—

Even with better-rounded integration in production under way and the rôle of steam-raising fuel oil shifted to a tapering use, additional gain will result from a constructive shaping of the demands for petroleum by-products so as to create a balanced outlet for the full values contained in the raw material. This accomplishment will depend upon a clear appreciation of the fundamental importance and tremendous significance of multiple production in general, together with a true perception of the peculiar nature of the problem that this matter presents. Since by-products represent a field of comparatively recent growth, very immature as yet, and since, moreover, the term tends to connote products of *incidental* importance, it may be well to visualize the rôle of by-products in industrial growth, so far as this may be done in a broad, general way.² In this preliminary measure of the field we will confine ourselves to those industries engaged in the breaking down of raw materials into products, as the by-product principles are most outstanding and conspicuous there, though they are less obviously applicable to a greater reach of industrial activities.

Industries, such as the mineral industries, engaged in the extraction of values from raw materials, have developed under the influence of demands for one or more products and only under ideal conditions, not easily attained, do those demands become balanced so as to cause full value extraction, that is to say, full utilization. Such industries, then, under simple and (industrially) primitive conditions produce one or more main products and waste products. The waste is produced arbitrarily and necessarily, and is discarded in lack of a demand calling for its use. As such industries develop, products of value come to be made from the so-called "waste"; the industry then turning out one or more by-products, in addition to the main product or products, and less waste. But the development of by-products is a slow and lagging growth, so much so that, by and large, an imposing loss of potential value accrues by this default. A fully developed industrial activity produces main products, balanced according to demand; by-products fully developed to current needs; no waste products. There are few activities in the United States that have attained this measure of effectiveness; perhaps the modern packing house is the most conspicuous example we can adduce.

In the course of industrial growth, the production of main products is under the control of a natural law whereby supply and demand seek mutually and automatically to effect a balance against

¹ The term "multiple product" is used to convey the idea of unlimited range of growth, a conception inadequately expressed by the word "by-product."

² This matter is exceedingly involved and complicated and can be presented here in broad outline only. A more detailed study of the rôle of by-products in the mineral industries is in course of preparation for publication later in this series.

disturbing external factors. The production of incidental products (waste products and by-products), however, is under no such control, but is determined by the output of main products. Hence the supply of incidental products exceeds the demand. Industry itself tends to bring these incidental products into use, but is limited by certain restrictive circumstances.

The individual industrial activity is often too small or poorly organized to make by-product recoveries, which usually gain their value from a cumulative effect only possible under large-scale operations. If the activity is strong and highly organized it tends to build up by-products, in so far as the by-products are end-products or near end-products; that is, materials that may be adapted by slight treatment to an immediate consumptive demand. Such activities may even add small pendant industries in order to make the adaptation. Such pendant industries, however, are usually confined to operations that may be largely fed by the output of the parent industry.

If, however, the potential by-products are of the intermediate order, requiring outside industries to carry them forward into use, and these outside industries are lacking, inadequate, or too foreign in scope to be built up by the parent activity, the matter of by-product development gets beyond the reach of industrial stimulus. Such is the case with the bulk of by-product possibilities. The parent industry can do little or nothing; independent industries to handle such materials are slow to develop, hampered by the uncertainties of a supply fluctuating independently of the pressure of their demand, and hesitating to build activities at the mercy of conditions beyond their control.¹

Apart from the virtual inability of an industry to create a favorable outlet for its potential by-products of the intermediate order, there is a lack of definite stimulus to do so, growing out of the fact that the loss involved in nondevelopment is not felt by the industry. Within an industry, it is true, where the lack of by-product recovery is due to the inferior practice on the part of an individual enterprise as contrasted with its rivals, the waste involved does mean financial loss to the activity engaged in the inferior usage, and is slowly remedied by the operation of continued competition. But where the lack of by-product recovery is common throughout an industry, there is no competitive spur toward improvement; and as the waste involved in the lack of full-value recovery is a loss not borne by the industry and not perceived by the public, who for the main products pay a price untempered by by-product contribu-

¹ There are other factors retarding independent industrial developments utilizing by-products, but these involve matters that need not be gone into here.

tions to joint cost, there is no activating motive to give the matter initial impetus.

It would appear, therefore, that by-product developments are under the influence of peculiar economic factors, and therefore demand treatment different from that accorded ordinary industrial affairs. Industrial initiative and competence face distinctive limitations in what they can do alone. These limitations lie in the field of industrial interrelationships, in the no-man's land between industries. These limitations can not be adequately overcome by any single industry; their elimination requires cooperative action, synchronized growth, between one industry and another, frequently, indeed, between a large number of industries of which some may not even be in existence. These delicately balanced intergrowths obviously require a guiding hand of wider sweep than any single industry affords. Here is a true governmental function, an untilled field for constructive economic policy to make productive. Upon this concept hangs the whole forward sweep of by-product development; and as the utilization of raw material is going forward, of necessity, on the basis of by-product recovery, we are here involved in a matter that may not wisely be overlooked.

It need not be considered here how far a constructive economic policy may advantageously go in this matter. But at least it should accord the problem the true weight of its importance, build toward effecting a proportionated industrial growth, gather an accurate record of the so-called waste products turned out by the industries of the country, and encourage the development of new industries utilizing products now going to waste. The lack of a constructive economic policy in the United States has not critically retarded the growth of ordinary industrial activities, in which, indeed, this country holds a foremost place; but it has been unfavorable to the proper development of all those industries involving by-product principles—the chemically controlled industries,¹ as they may be termed for want of a better name—in which this country, in spite of some notable achievements, has fallen notoriously short of her possibilities.

The whole matter of by-products growth has been retarded, also, by the general feeling that it represented a small incidental matter of no great moment.² But, as a matter of fact, the sum total of the possibilities embraced is of the most striking import, whether measured in dollars or in service to society. The capability of by-products to lower the cost of main products is perhaps a very direct measure of the public's concern in a policy competent to stimulate progress

¹ This term is intended to be broader in scope than the term "chemical industries."

² Anyone who has followed the chemical journals for the past few years would see no tendency to underestimate the matter, but these views, unfortunately, seldom reach the public broadly or the general press. Recent war-enforced interest in chemical affairs is changing these conditions slightly.

toward that end. No better example can be brought forward than the following table recently published by a large packing house showing how by-products contribute to lowered cost:¹

Average price paid for cattle, per steer.....	\$84. 45
Average price received for meat.....	68. 97
Average price received for by-products.....	24. 09
Total received.....	93. 06
Expenses and profit.....	9. 90

As to their social value—their contribution toward human conservation and welfare—modern civilization in the past few years has become utterly dependent upon the aggregate of by-product substances, which have already entered practically every realm of activity. Nay, more than this, civilization at this very moment of writing rests upon the competence of toluol, an obscure by-product of coal and petroleum, scarcely heard of a few years ago.

Applying these conceptions to petroleum, we observe that petroleum refineries at present produce:

	Proportion- ate bulk.	Proportion- ate value.
Four main products.....	<i>Per cent.</i> About 80	<i>Per cent.</i> About 90
About 200 by-products.....	About 15	About 10
Waste.....	About 5	None.

The petroleum refining activity is the largest and one of the most efficient chemically controlled industries in this country. Yet while the most competent branches of this activity have carried the production of the main products forward with effectiveness, they have not been able, alone, to draw more than a modicum of value from the by-product possibilities inherent in the resource. Aided by a constructive economic policy active in the direction of shaping a proportionated outlet for intermediate products and focusing a competent campaign of chemical research on the matter, the petroleum industry would be enabled to carry its by-product development much further, to the relief of the cost now so exclusively borne by gasoline, kerosene, fuel oil, and lubricants. Petroleum and coal tar are the chief raw materials of synthetic organic chemistry, and the values hidden in these two substances, as already so well known in the case of coal tar, can not be exaggerated in prospect.²

¹ Swift & Co., 1918 Yearbook, p. 32. This expression, of course, is conservative.

² Apart from the matter of by-products, the automotive industry can assist in maintaining a balanced outlet for the main petroleum products by bending its technical developments so as to fit the resource in the way of adapting its engines to handle a wider range of oils.

Encouragement of oil-shale development.—Although the present source of petroleum should be made to render its fullest service, we should at the same time find out what is going to take its place and prepare in advance for the transition, not ignoring the matter until it is forced by sheer necessity.¹ We have already seen that oil shale is the only successor in sight, and indeed some attention has already been devoted to this resource, especially as the richest part of it occupies land in possession of the Government.

But oil shale being a leaner resource than that now worked for petroleum is not a rival but an understudy to the oil field. A shale-oil industry will come into life when the situation is ready for its advent. A constructive economic policy will neither force its premature birth nor will it permit conditions to retard its inception and growth when once its help is needed to supplement an inadequate oil-field production. The oil-shale matter, then, is merely part of the whole oil problem and can not be solved on its own merits alone. Indeed, it has no merits other than those reflected from a growing scarcity of petroleum.

The oil-shale development will have to unfold under the influence of an economic necessity for shale oil. A constructive policy may contribute to that unfoldment in three ways, but further than that it can scarcely go safely or wisely.

It can, in the first place, stabilize the production of petroleum so as to place this resource on the sound basis of ordinary mining procedure. With this done, oil shale will face a resource with which it can cooperate, not an adversary which it must fight. So long as the oil fields of the country fill all the legitimate needs for petroleum products and contribute a large surplus for burning under boilers, there would appear to be no pressing need for shale oil.²

Secondly, the Government can prepare for the time when shale oil will be needed by establishing an experimental plant on a commercial scale, equipped to work out on a practicable basis, with full by-product recovery, the most efficient practice adapted to the conditions of the domestic resource. Such a plant could start with the technique developed in the Scottish shale-oil industry, and by proper research build up a process which would insure the home activity from taking over any obsolescent features of the Scottish practice or from passing through a stage of technological immaturity. This

¹ We must remember that this country, thus far, has never had to face the exhaustion of a great resource. A somewhat analogous experience is afforded, however, in the case of the virgin forests.

² It is obvious that oil shale, to be profitable, must yield a full complement of products. There is still an oversupply of petroleum in respect to that consideration. An artificially stimulated or premature production of large quantities of shale oil would encourage the perpetuation of the current wasteful method of exploiting petroleum.

step, too, by providing exact figures of cost would give needed information upon which plans for an industrial development could be built. With the petroleum situation under scientific guidance throughout, and the shale-oil process worked out, the successor to petroleum could come into action on the sound basis of engineering exactness, unencumbered by the speculative element of uncertainty.

In the third place, as most of the richest oil-shale areas are embraced in the public lands, the Government has the responsibility of either itself developing the resource or of delegating this duty to private industry. Since governmental operation of matters in the field of legitimate industry is outside the favor of public opinion, it is evidently necessary that the resource be made available to private development under terms favorable both to the industrial activities concerned and to the public at large. To this effect, it will be the function of an adequate administration of the matter to hold such lands open to legitimate development leading to production, but guarding them against entry for purposes of speculation or non-producing investment. This, in fine, will hold the resource receptive to the real need, when it comes, keeping the field free of hampering encumbrances. It is feasible to frame legislation at once that will advertise the fact that the oil-shale lands are definitely open for productive operations, but are not available under conditions of deferred or non-production. As to the size of operations, it should be borne in mind for the purposes of such legislation, that while well-rounded integration is not essential to oil shale in the same degree that it is in respect to petroleum,¹ effective operations will require a considerable outlay and hence should not be shaped arbitrarily to a meager scale.

Encouragement of benzol and alcohol development.—While there is no apparent need at the present moment for gasoline to be relieved of part of its duties by the production of substitutes such as benzol and alcohol, these products are now running to waste because of the lack of that need. Each year we are wasting—destroying—vast resources capable of producing motor fuel, because they are a little less convenient to utilize than the petroleum resource, although the latter is strictly limited in size. Only an inadequate policy would permit such sacrifice of ultimate value to the expediency of the moment, although such a procedure is of such common experience as to be looked upon as an economic necessity and hence justifiable. An analogy is afforded in the case of water power, which is still largely unused on the assumption that coal is plentiful and

¹ With oil shale the elements of wildcatting and competitive extraction are lacking; hence there is no necessity for haste of production, with its consequent waste. Also the conditions of shale-oil production can not support sustained overproduction, as with petroleum. There is no need, therefore, to adjust size of holdings to geological units.

hence that there is no need for water-power development; the blind adherence to this dictum, ignoring its inevitable bearing upon transportation, has probably caused sufficient disaster to arouse suspicion of its wisdom.

A constructive economic policy, then, will not ignore benzol and alcohol, but on the contrary will promote their use. Benzol, indeed, demands such consideration on its own account, for a market for this product must be built up to help carry forward the important matter of proper coal utilization, as explained in Part 1 of this paper. Alcohol, too, is not without claim on grounds outside the petroleum interest, for its fuel utilization would give an outlet to the growing number of distilleries going out of service, while its possibilities as to generation on farms and its peculiar adaptability to tropical conditions form considerations of considerable weight. But for the sake of the petroleum resource itself, it would not be unwise to bring some relief to the growing demand for gasoline, which unhelped must face eventual curtailment.¹

SUMMARY.

The petroleum resource stands out because of its limited size and decreasing availability, the growing importance of its products, and the notoriously high percentage of waste involved in its exploitation. According to conservative estimates, scarcely 10 per cent of the resource value is recovered under present conditions, while the unmined supply now available in the United States is only about 70 barrels to the person. A survey of the resource and of the industrial activities engaged in its development indicates that the bottom cause of the present wasteful employment of this invaluable resource is a lack of adjustment between economic circumstances affecting production, and the unique geological conditions under which petroleum occurs. The geological unit or reservoir, by nature indivisible, is arbitrarily subdivided into small parts for purposes of individualistic production. This discordance leads to a train of wastes that consume the bulk of the resource. Its cause may be removed by reshaping the method of production so as to fit with the occurrence of the resource, and the means for this accomplishment will come through development and application of a constructive economic policy.

The betterment of the situation, in the last analysis, depends upon the pressure of public opinion. The whole matter now rests upon

¹ It may not be beyond the interest of the automotive industry to bend its energies toward providing a situation where benzol and alcohol will come into action. Such effort, if undertaken, should merit popular support because of its constructive tendency; and in particular will it stand in need of sympathetic governmental help when it approaches the legal aspects of alcohol exemptions.

an unsound basis. The exploration for petroleum is guided by the principle of gambling. The extraction of petroleum is dominated by the principle of robbery.¹ The utilization of petroleum is conditioned, in part, by the principle of perversion. Society has put its ban upon these principles as applied to superficial matters. How long before their unsoundness will be recognized in respect to a basic necessity of life?²

¹ Not *robbery*, but the *principle of robbery*; competitive extraction of petroleum within single reservoirs is legalized and in good repute.

² The writers desire to acknowledge their indebtedness for valuable information on petroleum to the publications of the U. S. Bureau of Mines and the U. S. Geological Survey, as well as to personal communications from many individuals, including Carl H. Beal, Chester Naramore, John D. Northrop, David T. Day, H. S. Dennison, and R. D. George.

PART III.

POWER.¹

In the struggle for existence man has attained superiority through a facility for turning the forces of nature to account. In modern life the expression of this facility is industrialism—the cooperative employment of mechanical power for useful work; the delegation of service to machines energized by coal, oil, and water power; the organized gaining of a livelihood. Mankind is therefore dependent upon industrialism and industrialism is contingent upon a supply of power.² Power represents the substitution of mechanical energy for human energy, of mechanical work for human labor.

INFLUENCE OF POWER UPON CIVILIZATION.

Modern nations expend far more energy than the combined muscular ability of their populations and beasts of burden. The margin is covered by the employment of mechanical energy in the form of power. To accomplish the work done annually in the United States, or at least the equivalent in such kind as men could perform, would require the labor of three billion³ hard-working slaves. The use of power gives to each man, woman, and child in this country the service equivalent of 30 servants.³ Modern civilization arises from this organized employment of mechanical energy.⁴

¹ A contribution to the solution of the transportation problem.

² Industry requires raw materials, power, and labor, and is activated by business enterprise. The factors concerned in the supply of raw materials and power are no less important than the human elements of labor and business enterprise, though the former have thus far received attention far short of their deserts. The fact that the reserves of raw materials are decreasing and the conventional sources of power are shifting, while both the potential supply of labor and the scope of business enterprise are enlarging, make for a situation in which raw materials and power must come in for considerable attention. It is with this prospect in mind that the present series of papers (parts 4, 5, and 6 of Bulletin 102) have been written.

³ These figures are very rough, based on an assumed power utilization of 150,000,000 horsepower (which may be fairly wide of the mark) and the equivalence of 20 man-power for 1 horsepower. As a matter of fact, this country has no adequate record of its total power consumption. The conventional man-power equivalent of 1 horsepower is 10, but taking into account the fact that man-power can not be sustained, the ratio of 20 to 1 is chosen as representing a fairer comparison.

⁴ "The power of Greece, whereby she achieved such great things in all directions of human progress, was largely based on the work done by the servile class. On the average each Greek freeman, each Greek family, had five helots whom we think of not at all when we speak of the Greeks, and yet these were the men who supplied a great part of the Greek energy. In Britain, we may say, each family has more than 20 helots to supply energy, requiring no food and feeling nothing of the wear and tear and hopelessness of a servile life." (James Fairgrieve, *Geography and World Power*, 1917, p. 316.)

The social response to the use of power is a departure from the individualized self-reliant order of livelihood and a steady advance toward the centralized integration of service which we now know under the familiar guise of industrialism. Whether taken in the whole or viewed in a single community, the outcome is the same. An example drawn from pioneer conditions will serve to illustrate the simple course of development. A machine suitable for doing the work of several hands is capable of filling the needs of several individuals. Introduced into a community dependent upon hand labor, such a labor-saving appliance tends to centralize the work falling within the scope of the machine. The operator, becoming proficient and finding himself looked to for an increasing measure of service, adds to his equipment. At the outset he performs only the work brought to him by individuals in the community, who supply the raw materials and receive in return the finished products. Soon, however, the competence of the machine becomes more widely recognized and the operator is commissioned to supply the raw materials as well as the service. Presently, again, with the recurrence of such commissions, the operator goes further, and instead of awaiting specific commissions assumes the initiative in providing both raw materials and service in anticipation of demand, and thus an industry, in the current sense, is launched. Such has been the run of evolution in the rise of industrialism, and wherever individual work persists to-day it is in process of giving way in favor of the community operation.

The use of power not only leads to centralization of work, but the form in which power is available determines the type of industrialism or civilization that develops. Considering energy apart from its sources, we find that this force has come into use in three mediums of expressions—liquid, gaseous, and nonsubstantial—typified in hydraulic power, steam power, and electric power. These steps in energy usage represent progressive stages in facility of employment and indicate an evolutionary trend underlying the industrial unfoldment to which they have given rise. Thus the use of hydraulic power marks the period of individualism which prevailed the world over until the eighteenth century, and still holds in all but the so-called civilized nations; the application of steam power instituted a change so profound as to merit the name "The industrial revolution," and colored the whole face of modern civilization during a stretch of time, extending to the present, which may be termed the formative period of industrialism; while the introduction of electric power brings forward a third advance in power usage offering to the maturing aspects of industrialism a special service needed to carry forward its complex and constantly enlarging

activities. Just as steam power opened up the coal fields of the world and freed the employment of power from the geographic restrictions inherent in the use of the pressure of falling water, so electricity reinstates water power on terms of equality with coal, offers the means for the transmission of energy devoid of bulk, and affords a readiness of subdivision and ease of application that considerably enlarges its range of applications.¹

Thus the third and current stage in the growth of power utilization, and that is to say, of industrialism, is marked by the introduction of water power on terms of parity with coal, by the establishment of facilities for extracting energy from coal at the mines and transmitting it to the points of use, and by the development of means for greatly facilitating the range of service that energy may be called upon to render. It will be observed that although the three lines of advantage have been open for some years, the first has met with but partial acceptance, the second has been entirely ignored, while only the third has enjoyed any considerable measure of service. This status of affairs, of course, is the outcome of commercial selection, but it is desirable to examine whether industrialism can continue to grow in adequate measure without utilizing more fully and comprehensively the opportunities held out by electricity.

RELATION OF POWER TO TRANSPORTATION.

The United States places special emphasis upon the use of power. With national prosperity, abundance of resource wealth, and dearth of labor, American industrial enterprise has naturally turned to the creation of labor-saving machinery and provided for its efficient employment through the medium of standardized volume-production. Thus the fabric of American industrialism is colored by the machine process and the large-scale operation to a degree not equalled elsewhere in the world; while mechanical appliances and mechanical service have reached out into domestic life in a pervasive manner. These conditions have created and sustained a scale of living without parallel amongst other nations. To support this situation, this country consumes nearly half of the world's output of coal and over half of the total production of petroleum, not to mention the employment of water power, natural gas, and minor sources of power.²

¹ The advantages of electricity arise from the fact that this strange and even mysterious manifestation of energy is virtually energy itself—not energy locked up in a material condition and subject to the laws and limitations of matter, but energy, the capacity to do work, freed from substantial form.

² Of the coal and oil consumed, only about two-thirds goes into the production of motive power, although much of the service outside this field is closely related, such as the production of heat, light, and chemical work. Before the war the consumption of coal in this country was between one-third and one-half of the world's total; the proportion is now approaching one-half.

This unprecedented consumption of power, of course, places a heavy strain upon transportation, both directly by virtue of the bulk of the power materials to be moved—coal alone represents over a third of the country's freight—and indirectly in respect to the haulage of materials and products involved in the industrial processes. The responsibility thus falling upon transportation is added to in further degree by the size of the country. The presence of a population scattered over a vast area, with a standard of consumption cut to the measure of a concentrated industrialism, attaches the element of distance to the factor of bulk and imposes an accentuated dependence upon adequate carriage.¹ Thus in two respects the transportation problem in the United States is unique.

But national dependence upon transportation, so highly developed by virtue of the advanced state of industrialism and the areal extent of consumptive demand, is increasing. The rapidly enlarging use of power and the growing burden of commodity haulage arising in consequence, to say nothing of the claims of foreign trade, give no prospect of letting up. Every time an individual adopts a mechanical appliance or purchases an article hitherto made at home or gone without, thousands of others are doing the same thing. Society will not turn back now; presently it can not turn back any more than it can to-day weave its own garments by hand. The convenience of to-day is the necessity of to-morrow. If we project the present trend of requirements even 10 or 15 years into the future, we begin to gain a true perspective of the imposing weight of the transportation problem that industrialism faces.

Since transportation is called upon to bear a heavier responsibility in the United States than is the case elsewhere in the world, it should be observed that there is an element of weakness in the functioning of transportation which becomes the point of break under strain and therefore merits particular attention in this country. This is the matter of differential elasticity as between the operations of industry and transportation, which prevents an equalized stretching of the two. For example, when a ton of material passes through a manufacturing plant it means, with due qualifications, that the railroads have hauled a ton of raw material from far and wide and will move a similar weight of products away for distribution. Thus each increment to the volume of manufacture creates a twofold addition to the volume of transportation. Induce a stress of industrial expansion and the stress communicated to transportation is correspondingly magnified. The fabric is mechanical in each case; but the fabric of industry is woven with the maximum of elasticity, while the fabric of transportation is inherently more rigid. Thus

¹ This has nothing to say of further complications in the way of conflicting currents of haulage arising from topographical conditions, etc.

one of the knottiest problems in the whole advance of American industrialism has been involved in the necessity for providing the requisite capacity on the side of transportation. The problem is serious enough at best. But when the item of power in the form of freight-hauled coal is added, the requirement calling for additional elasticity in the mechanism of transportation is almost doubled a second time, and the situation becomes well-nigh impossible to meet. So long as power is provided by means of freighted coal in its present heavy proportion, the transportation of the country is bound to cause serious trouble, if not to break down, during every period of sudden industrial expansion.

The relations of balance, as given above, are not in strict accord with statistical figures. Various other factors come in to qualify the figures, and incidentally to complicate the issue beyond the reach of simple analysis. Nevertheless the contrast noted is indicative of the general situation. The requisite degree of elasticity has not been attainable for transportation, and the lack of it has become increasingly conspicuous with the growth of the industrial order. The tendency has been to provide a surplus of slack in lieu of elasticity by maintaining facilities of transportation in excess of normal requirements. Such a condition constitutes a standing invitation to inefficiency and wastefulness, tending in the long run to nullify the potential advantage of readiness for industrial expansion, and hence is forecast for failure when put to the test. With industrialism less mature and less aggressive, these matters were less conspicuous, but their untoward propensities under present conditions of growth are becoming steadily more pronounced.¹

Thus transportation is the neck of industry through which all of its materials enter and emerge. Upon the size and flexibility of this throat depends the rate at which industry can grow. Pressure here acts as a throttle; if severe, there results congestion, choking, even strangulation. Transportation, then, is crucial. Either we must pay unremitting attention to facilitating transportation by every means available, or else be prepared to see industry retarded

¹ The current situation in the United States does not differ fundamentally from that abroad, although the consequences have not appeared in equal measure in the two instances. The disparity is one of degree; but the unusual weight falling upon transportation in the economics of American industrialism has turned this difference into high significance. The outcome appears in present conditions: the United States has been building a bulky and cumbersome fuel requirement, incapable of sustained growth, ready to fail under influence of rapid industrial expansion, and due to display its weakness, on the first occasion in the breakdown of organized transportation. This is not to be regarded as offered in specific explanation for the trouble this country is experiencing as an outgrowth of the war. As a matter of fact, the present work was projected over a year ago and the summation of conditions set forth above was outlined at that time. Its purpose in respect to present difficulties is in the direction of diagnosing an organic weakness which rendered the country peculiarly susceptible to attack by the disrupting influences now so unconcernedly borne on the basis of a passing trouble.

and slowed down at this point, with a fall in the scale of living and a change in the color of national advance. Thus far this country has attempted to meet this issue almost solely by means of railways, and has ignored the bearing upon the matter of the item of power, although this ingredient engages over a third of the freight capacity of the country and is a prime contributor to the inelasticity of the transportation fabric as now woven. From a broad viewpoint, it would appear that the transportation problem can not be adequately solved without giving due attention to the question of power.

Conversely, power itself presents a problem of no small magnitude, since without adequacy in this respect the processes of industry are idle. It is common notoriety that the limiting factor in the supply of power is not a dearth in energy resources, of which, indeed, this country is amply provided,¹ but lies in the means for getting the energy distributed to the points of use. The importance of the transportation side of the power problem is reflected in the country-wide system of pipe lines for the service of petroleum, and the concentration of industry in regions provided with coal—both concessions to the exigencies of carriage.

Thus, since the transportation problem embraces the matter of power, while the power problem displays itself mainly in the guise of transportation, the two issues merge, and whether viewed from the one angle or the other, the logical objective for an attack is presented in the form of power transportation.

PRINCIPLES OF TRANSPORTATION AS APPLIED TO POWER.

Organized transportation differs essentially from the simple individual act of carrying only in magnitude. The underlying principles are the same in the two extremes. Whether the concern be that of a stone in a neighboring field or a mountain of copper ore a thousand miles distant, effectiveness of transportation involves the same three factors. These are:

1. The employment of the equipment best suited to the task.
2. The advance elimination of superfluous weight.
3. The full utilization of the material transported.

The individual encounters these principles at every move and habitually follows their promptings in conserving his personal efforts. The operation of industry as a whole is also fashioned in conformance with them. The developments in the case of power supply provide the only noteworthy exception. Here the practice is at variance, not merely with one of the principles, but with all

¹ So large are the energy resources of the United States that their very size has made it seem unnecessary even to regard power as a national problem. Hence the problem has actually come to a head in all its seriousness, without any symptoms having generally been recognized in advance.

three of them. The energy in coal, for example, is not concentrated before shipment, but is hauled in its substantial, bulky form; while the coal at its destination is not used so as to yield anywhere near its full service.¹ With industry in general, conformance with these three principles has been automatic, a natural outgrowth in connection with the development of the various types of operations; with power supply, on the contrary, a sufficiency of natural incentive toward such an outcome has evidently been lacking. It is desirable, then, to seek to determine what is back of this apathy in the exceptional instance of power.

The first of the three principles of transportation, the employment of suitable equipment, involves a community interest. The facilities best suited for bringing to the market the corn raised by one farmer will haul grain from the entire corn belt with equal ease. Moreover, with slight qualification, the same facilities will serve to transport all the material necessities of the region. Hence there have developed common-carrier systems, represented chiefly by the railways, to which the performance of this function is delegated. These common-carrier systems, it is needless to say, are essential to modern conditions and derive their existence from the community interest which they represent. In consequence, the element of competition, which is the exact antithesis of community interest, is entirely out of place within the confines of such an activity. In the nature of things, accordingly, any response to the promptings of special interests amounts to a violation of a trust. Formerly this was not fully realized, and it has not been long since the evil influence arising from the promptings of special interests within the great common-carrier systems of the country was playing havoc with American industrialism. It is now firmly established, however, that the great arterial complex of transportation is founded on the principle of community interest and must be maintained in scrupulous accord with that principle. In the violation of this trust a common carrier has in itself the power to make or break any industrial enterprise, hence the method of control must afford the maximum assurance that the trust will not, and can not, be violated. Thus the successful application of the first principle underlying effective transportation, from a national viewpoint, requires a common carrier system not only adequately equipped as to organization and mechanical facilities, but of public-service integrity established beyond question of doubt.

The second principle of transportation, the advance elimination of superfluous weight, is a matter requiring individuality of treatment throughout. The conditions here are the reverse of those pertaining to the actual facilities of transportation. The responsibility attaches

¹ See Coal: The resource and its full utilization, Bulletin 102, Part 4, of this series.

to individual activities; there is no community of interest in the matter; the responsibility may be ignored, but it can not be delegated. In the realm of industry, competition affords the incentive for meeting this responsibility. The incentive, in general, has been sufficient for all practical purposes, and the specific application of this principle constitutes one of the chief interests in the shaping of industrial enterprise. Since power is a mineral derivative, the mineral industries provide a logical field for comparison. Here is found scarcely an instance of consequence where the raw mineral values are not concentrated to their utmost before shipment and where every available refinement of procedure is not employed toward the advance elimination of weight. The whole field of ore dressing has grown up under the incentive of this principle, not to mention the applications of metallurgy in this respect. The only noteworthy exceptions occur in rare connections, where competition for the placement of the end-products is a negligible factor.¹

The third principle of transportation calls for the full utilization of the material hauled. American economic practice has regarded this, along with the advance elimination of weight, as a matter to be left to industrial determination and application. This policy is natural enough and, in general, works out satisfactorily, for the two principles are complementary. What is usable at the manufacturing end obviously determines what represents value and non-value at the raw material source; conversely, the degree of separation practicable at the source specifies the range of material for which use is to be sought. The whole epoch-marking development in the field of by-product manufacture finds much of its stimulus in the effort to derive returns from what would otherwise be the waste in transportation. But, with certain notable exceptions offered by some of the large industrial combinations, there is much to be desired and little to be proud of, so far as American achievement in this direction goes. The superfluous transportation that results from the failure at the manufacturing end to make full utilization of the whole range of values held in the raw material hauled amounts to many millions of tons each year. Instances are plentiful where the loss is due to a blind nonrecognition of opportunity on the part of the interests directly concerned. But in the main the default rests upon the in-

¹ Perhaps the most notorious example of failure on this score is afforded by anthracite coal during the war-time stress, when millions of tons of waste slate were permitted to accompany the outgoing shipments of coal from the mines. The same thing was essentially true of bituminous coal during this period, only, as bituminous coal in the natural state is cleaner in respect to slate than is anthracite, the relative proportion of waste hauled was less in the case of soft coal. The outcome, then, should be accredited more to natural conditions than to lack of enterprise in this direction on the part of the bituminous producers, who, in common with the anthracite producers, displayed a ready response to the temporary nullification of competition as regards the placement of their products.

adequacy of American economic practice, which relies upon competition and the automatic working of the natural law of supply and demand to bring all good things to pass, neglectful of the fact that in the by-product realm supply is conditioned otherwise than by demand, that pending the creation of a proportionated demand the discrepancy of overweight on the side of supply is rejected as waste.¹

In such manner have the three principles of transportation developed in American economic practice. In the realm of common carriage, competition has been found to be out of place and is no longer relied upon, community interest taking its place. In the realm of advance preparation, competition has proved effective; and its free operation there is desirable. In the realm of full utilization, competition alone has been unable to achieve adequate results; and the need for constructive help to make competition effective here is coming to be recognized. These principles have registered among mineral resources in the main; they have failed dismally to find lodgement in the field of power resources. It remains to determine why the contrast and what the remedy. In the attempt, the three aspects of the situation will be considered in the reverse order of their presentation above.

FULL UTILIZATION OF POWER MATERIALS.

ROLE OF MULTIPLE PRODUCTION.

The power materials are coal, oil, and water, and, in the present connection, it is desirable to examine how fully the amount transported is utilized. Water, of course, is not carried considerable distances for purposes of power generation and therefore presents no problem in this connection. Oil, on the contrary, is in part inadequately utilized, but this matter involves many complexities, which are given in detail elsewhere² and accordingly may be passed over without further comment here. This limits our consideration, under the present head, to coal.

Current demand calls for the annual transportation and distribution of about 700 million tons of coal.³ Much of this demand could be satisfied with no other commodity or form of energy, while any change in the part open to modification can take effect only slowly.

¹ This important matter is examined in greater detail on pages 95-98.

² Petroleum: A resources interpretation, Bulletin 102, Part 6, of this series.

³ In 1917 this country produced 640 million tons, but the requirements for 1918 will be over 700 million. While roughly only two-thirds of the output is used for power generation, the other third being employed for the manufacture of coal products (chiefly coke) and for domestic heating, the principle of full utilization applies to the total amount.

Meanwhile the demand is increasing at the rate of some 50 million tons each year. The expansion in new consumption, then, may fairly be expected to offset any curtailment in bulk that betterment of procedure may permit. The best that may be hoped for is a check in the growth of the coal burden under which organized transportation is already staggering. To let this burden freely continue to increase, trusting the outcome to luck, is to court all kinds of trouble, if not disaster; yet, even with best effort, there is little prospect of a diminishing requirement.

It would appear, therefore, that at best we must continue to deal with over a half billion tons of coal. This figure, then, may be taken as representing the minimum of actual demand that must fall upon transportation, the minimum of tonnage whose full utilization in consequence is called for. Primarily this enormous amount of coal is now consumed in order to gain the energy contained in it, all else being disregarded. But coal is something more than energy in material form; it is also a source of many valuable mineral products. Indeed, it is a veritable treasure house of values, in this regard far surpassing any other type of mineral substance.¹ Upward of a thousand coal products are in use to-day, some of them filling needs less conspicuous but every bit as vital as that for fuel. And the development is still in its infancy. A few years ago and few of these products were known. Chemical vision can see no limit to the further unfoldment in prospect. The boundary to this field is like the horizon, always in sight but never to be reached. There can be no full utilization of coal which fails to take these matters into account.

At the present time a very small proportion of the coal consumed is adequately used. Putting to one side anthracite, which has an energy value merely ² and therefore yields a reasonable service in its crude state, and counting off about one-twelfth of the bituminous coal, the portion subjected to by-product recovery in connection with the manufacture of coke, we find that there still remains each year in round numbers a half billion tons of coal which are consumed in the raw condition with a total loss of the commodity values and an incomplete recovery of the energy. The sum total of this loss represents the margin between present attainment and full utilization, and may be presented in tabular form, as follows:

¹ With the possible exception of petroleum.

² Its commodity values were lost in the course of its strenuous geological history.

TABLE 1.—*The neglected opportunities involved in the wasteful use of coal in the United States.*

[All figures in round numbers and on an annual basis.]

PRESENT ATTAINMENT.			POSSIBLE ATTAINMENT.		
Coal inadequately used under present conditions (1918).	Recovered under present conditions.	Available under present technical knowledge and ultimately recoverable under stimulus of constructive economic policy.	Loss interpreted in terms of dollars on basis of normal (1915) values.	National meaning of loss under present circumstances.	National gain from correct practice.
	Energy.....	At least double the present recovery. (On basis of widespread utilization of gas in place of solid fuel, etc.)	\$1,000,000,000+ in needless mining and transportation of coal.	Needless burden upon overworked railways. Smoke nuisance in cities, entailing untold destruction of civic betterment attainments. High cost of coal to consumer. Resource waste.	Some relief to transportation. Complete elimination of smoke. Cheaper fuel.
	Nitrogen (ammonium sulphate).	5,000,000 tons. (On basis of 20 pounds per ton coal.)	\$280,000,000.....	Serious nitrogen problem affecting field of fertilizers and explosives. Dependence upon Chile for sodium nitrate. Large expenditures for atmospheric-nitrogen plants. High cost of nitrogenous fertilizers, reflected in cost of food.	Nitrogen independence, contributing to food production and explosive manufacture.
500,000,000 tons.	A small percentage of the energy.	Benzol.....	1,000,000,000 gallons. (On basis of 2 gallons per ton coal.)	Undue dependence upon gasoline as motor fuel, contributing to overproduction and rapid exhaustion of the petroleum resource.	Contribution to supply of motor fuel. Advancement of good-roads movement. Establishment of large coal-products industry. Gains in new directions to be developed by chemical research.
		Tar.....	4,000,000,000 gallons. (On basis of 8 gallons per ton coal.)	Neglect of roads.	
		Total..	\$100,000,000..... Additional value of coal-products manufactured from benzol and tar. a\$2,000,000,000.....	Inadequacy of coal-products industries. Problems in explosive manufacture.	Capacity for relieving cost of living \$10-\$20 annually per capita. Gain to American industry.

^a This figure is given as a concrete expression of the magnitude of the opportunity that faces this country in respect to coal, although the significance of the prospect is conveyed more truly in the two columns to the right. The matter, of course, can not be expressed in figures without qualifications, which, therefore, must be accepted on a basis of the argument in the text. An element of double count in the summation is compensated by increments resulting from the course of advancement in multiple production.

The question naturally arises, why this preponderant inadequacy in coal utilization? This is no simple matter to explain: the reply that the individual user, whether an industry, a community, or a householder, finds it cheaper to consume raw coal than to dispose separately of its various values is true, but superficial. That procedure is not cheaper for the users in the aggregate; also there is no lack of technological knowledge requisite to fuller recovery of the values in coal. The shortcoming, then, can not be due to lack of desirability or to lack of technique. The default must be credited against economic conditions. And since the United States in the past has possessed no activities engaged in shaping and stimulating industrial developments, the responsibility reduces itself to the fact that industrial enterprise has not seen fit to go into the matter. Either the opportunity has not been apprehended or industrial enterprise, cognizant of the situation, has not been interested. The latter is undoubtedly the true explanation.¹ For this lack of industrial initiative a blend of several factors is responsible. In the first place, America has been full of opportunities for volume production, and consequently business enterprise has not been forced by the stress of narrowing industrial opportunities to turn to the far more complex field of multiple, or by-product, production; only where the opportunities afforded in this direction were outstanding and marked has the inducement been responded to.² Secondly, any given project, on contemplating the prospect, faced a situation in which the establishment of production would yield by-products, the consumption of which required other industries which in turn would contribute other products calling for still further activities; hence a project at the source would undoubtedly see their contemplated output ranging off into hypothetical regions not yet established; while a project, viewing the matter further out, would regard its proposed position as bearing some resemblance to an island in a sea of nondevelopment. The requisite reach of coordination was evidently not self-accredited on the part of industrial enterprise. Then, again, the field has opened up fully only of late, so that the full measure of the opportunity has not been long standing.

In addition to these considerations, there has been no competitive spur to action. The loss represented in the wasteful consumption of raw coal was not felt by any given industry, since the practice was universal and the cost under this head was a more or less uniform item which was shifted in its entirety to the shoulders of the con-

¹ Industrial enterprise has been interested to the extent of bringing multiple production into about half of the coke industry, but here the opportunities are particularly favorable.

²As in the case of by-product coking, petroleum refining, etc.

suming public.¹ The need for advance was also not generally appreciated, inasmuch as there was plenty of fuel, transportation difficulties had not loomed up, coal products could be purchased from Germany, nitrate could be imported from Chile, and, in general, the whole matter of coal was taken for granted.

Hence industry had no particular incentive for entering into a new field which, while large, was intangible; moreover industry, under the old order, faced decided limitations in its recognized inability to construct a *proportionated* demand for the whole range of prospective products. On the other hand, the public, which was actually paying the cost of the inadequacy, but under a disguised heading, did not see its concern in the matter, nor was public interest represented by machinery charged with acting on popular behalf; public utilities commissions, the nearest approach to such machinery, were notoriously weak and shallow; the Federal Government, lacking the pressure of public opinion, did not take up the issue. So the course of progress was short-circuited, and the tremendous possibilities in our unrivaled coal resources remain to-day practically untouched. The industrial progress of this country has been sustained by the mining of an ever increasing quantity of coal, until the very bulk of the total has become a critical weakness in this country's industrial life.

Such is the situation. The utilization of coal is extravagantly wasteful from beginning to end, the wastefulness is a matter of uniform practice not subject to improvement through avenues of individual enterprise, and, contrary to general notions, it is the public at large, not industry itself, which stands the loss from the shortcomings in the situation and which is, therefore, primarily concerned in its betterment.

The public is concerned because it pays the bill rendered by present wastefulness and will reap the gain accruing from any progress toward competency. The net advantage will not merely represent the margin of value now lost, but in addition will include the border of advance added by the multiplication of values over those calculable from the standpoint of the present. The total gain can not be expressed in terms of exact figures; indeed, it is in no sense a fixed quantity, but entirely dependent upon the length to which the future carries the matter from its present chaotic stage. But apart

¹ In the realm of industry, where wastefulness is a matter of scattering individual practice, the industrial offender pays the direct penalty of loss; but where wastefulness is a matter of uniform practice and is the rule, the whole burden of loss falls upon the consuming public. Ordinarily, the stimulus of competition works automatically to undermine inadequacy and prevent its permanent establishment in uniformity of practice. But if natural obstacles in the path of industrial enterprise render individual activities powerless to proceed in any other than the wasteful direction, nothing operates to prevent the rule of incompetence from becoming a stabilized convention.

from the prospect of future gain, the maintenance of the situation as it now stands is actually costing money. There is no apparent reason why fully coordinated development should not look toward a fairly complete recovery of at least the leading by-products¹ in coal, and this prospect would definitely entail the doubling, if not the trebling, of the fuel efficiency derivable. This means that our present annual coal output could be made to more than double its service, or, accepting the current service requirement as a standard, that less than half the output can do the present work and in addition make heavy contributions to the supply of fertilizers, motor fuel, and chemical products. The aggregate loss, on the basis of this very modest estimate, runs well above a billion dollars a year, or over \$10 for each inhabitant of the United States. (See Table, p. 113.) Of such measure is the average man's pecuniary interest in the full utilization of coal.

Improvement in coal utilization, then, can not be relied upon to come from industrial stimulus alone, but must be brought into effect as the result of public interest in the matter. The means for starting toward this accomplishment are set forth in Part 1, as lying in the direction of enlarged municipal gas plants, which will handle all the coal needed by the community with the production of solid fuel, gas,² and the by-products, ammonia, benzol, and tar.

Through the principle of multiple production, therefore, coal can be forced to render up its full quota of service. This is a new economic force, one scarcely recognized as yet as a principle which may be constructively applied. Yet the principle of multiple production has been gaining headway for years, and by means of it the multiplying needs of man are being met from practically a stationary range of raw materials. The rôle of multiple production is rapidly enlarging; it represents a principle that must come into play more and more to relieve the strain falling upon natural resources and transportation. Through the agency of chemical knowledge it serves to create a divergence of products, each the starting point of a second diverging series. The principle of multiple production is peculiarly applicable to coal and oil; only by the use of this principle, brought into effective action under the guidance of a constructive economic policy, can adequate value be extracted from these power materials.³

¹ Nitrogen, benzol, and tar.

² Or the energy may be separated from the commodity values wholly in the form of gas.

³ The whole matter of multiple production, a term of broader significance than the more familiar one of by-product production, is discussed in detail in Parts 1 and 2 of this paper. The coming in of multiple production as an economic force will cause a revision in some of the popularly accepted ideas of economics, especially as regards the operation of the "law of supply and demand," as the reactions in the neighborhood of multiple production are different from those occasioned by volume production.

RELATION OF MULTIPLE PRODUCTION TO ELECTRICITY.

The principle of multiple production and the principle of electricity are the two most important economic forces that have come into play during the current industrial order. Nothing since the introduction of steam power can be compared with either of them in significance. Both are radically at variance with the established order; both have a special bearing on the power supply as affording untold possibilities for marked betterment. Neither has won recognition in this field provocative of notable change in the basic conventions of procedure. Here each alike has been ignored, except in so far as its advantages have gained lodgment within the establishments of precedent. Of the two electricity has made the greater headway; multiple production has not yet found an opening outside the confines of the coke industry and has succeeded in preempting only half of that field.¹ Neither electricity nor by-product coal utilization has entirely been neglected, but the real possibilities for the common good so bountifully contained in each have never been cultivated in the least.

In the realm of power these two great agencies of economic advance are exactly complementary. Together they present a solution for the transportation aspects of the power problem, not to mention their bearing in other regards. The principle of multiple production enables the full utilization of the whole range of values transported in the form of coal. Electricity makes it possible to transmit *energy* where energy alone is required and thus frees the ordinary channels of transportation of a needless burden of bulk haulage. The first would determine the amount of coal needed and insure the adequate employment of that amount; the second would make it unnecessary for the railways to haul more than the amount thus determined. The outcome merely waits upon the application of these two economic forces in effective coordination.

POWER RESOURCES AND ADVANCE ELIMINATION OF WEIGHT.²

Before the advent of electricity energy was inseparable from a material expression, and the economics of power usage grew up

¹ The gas industry weighs but lightly in this connection, as this activity consumes only about 1 per cent of the bituminous coal production, and in this field multiple production has scarcely started. The principle of multiple production, however, spells the future—the only future, but that a great one—for the gas industry.

² Oil is left out of consideration, for the present purpose, as involving a highly specialized field which can not be gone into here without an unwarranted digression; besides, this matter is treated in detail in Bulletin 102, part 6, of this series. Counting off the use of gasoline and other light oils for automotive purposes (a field of power application not ordinarily considered in connection with the problem of industrial power), there is a formidable and growing quantity of fuel oil that is devoted to steam raising; large areas of the country, indeed, not within easy reach of coal fields, are served by fuel oil to the almost complete exclusion of coal, while even within the coal territory fuel oil has replaced coal to some extent. But the character of the resource indicates that the growth of fuel-oil employment is of a mushroom order; with a capacity for infinitely greater refinement of function, its use for the brute force of industrial power is a perversion which can have no permanent place in the category of progress. Though transiently a competitor to coal and water power, oil is fundamentally a supplementary resource; its degree of overlap now represents the measure of its perversion.

under the exigencies of this dependence, as illustrated in the distributive use of coal. But now a command of the electrical principle makes it possible to deal with energy freed from substance. This not only concerns coal by providing the means for extracting the energy at the point of production, instead of at the many points of use, to the gain of efficiency and the saving of transportation; but it applies also to water power, a resource hitherto fallen into disuse because of its inability to cope with coal, but reintroduced by electricity upon more advantageous terms, to the practical gain of a new energy resource. In spite of the fact that electricity has been in common and growing use in this country for many years, it has effected practically no change in the basic conventions of coal usage and has led to the development of a small fraction merely of the available water power.

Since electricity has rehabilitated water power, thus making available two energy resources where there was only one before, it is desirable to determine the resource status of water power as compared point for point with coal power, for the two are coming, of necessity, into competition, and unless water power in its new habiliment can stand on a reasonably equal footing the outcome of the competition is bound to fall in favor of coal, as occurred before when steam power drove hydraulic power to the wall. In which event water power, in spite of its ethical advantages, would have no special significance for the present.

In respect to the size of the resource reinstated by electricity, there can be no fault to find. Efforts to determine its magnitude have led to estimates placing the possibilities of hydroelectric development in the neighborhood of 200 million horsepower, of which some 50 million is capable of use without special provisions for storage.¹ Expressed in another manner, the water power of the United States, converted to electrical energy, is more than capable of turning every industrial wheel and illuminating every street and building in the entire country. Also the resource is country-wide in distribution. (See fig. 14.) The apportionment amongst the various sections is by no means even, but the supply is more widely and equably spread than is the case with the coal fields; and the regions distant from the sources of coal are all bountifully favored with water power. Thus New England, the South Atlantic States, the Southwest, and the Pacific slope, together embracing over half of the potential water power of the country, are all practically without coal and bear testimony to this complementary distribution of power resources. (See Table, p. 119.) This balanced occurrence has considerable bearing

¹ The discrepancies in the various attempts to inventory the water-power resources of this country are due to several qualifying factors, notably that of storage. Since the demand for power is commonly uniform the year round, the capacity of a given site for sustained effort is determined by the period of minimum flow. Accordingly, storage provisions doubling the flow merely during such periods will double the year-round capacity.

upon the welfare of the Nation, as treated in some length under "Nationalization of industrial opportunity."¹

Table showing distribution of water power in sections lacking in coal.

[Figures approximate and given in round numbers.]

	Potential water power (percentage of total in United States).	Unmined coal (percentage of total reserve).	Unmined oil (percentage of total reserve).
New England States (Maine, Vermont, New Hampshire, Massachusetts, Rhode Island, Connecticut).	3 per cent.....	None.....	None.
South Atlantic States (Delaware, Maryland, Virginia, South Carolina, Georgia, Florida).	6 per cent.....	1 per cent (practically all in Virginia and Maryland).	None.
Southwestern States (Arizona, New Mexico, Texas, Oklahoma, Arkansas, Louisiana).	6 per cent.....	4 per cent (mostly in Oklahoma and Texas).	52 per cent. ^a
Pacific States (California, Oregon, Washington).	43 per cent.....	2 per cent (mostly in Washington).	31 per cent.
All other States.....	42 per cent.....	93 per cent.....	17 per cent.

^a Includes Kansas.

But in spite of the advantages of size and wide distribution enjoyed by water power, this resource has not been able thus far to enter into serious competition with coal. Only some 10 per cent of the total expansion in power consumption in recent years has been in the direction of water power. The present production of hydroelectricity in the United States represents roughly the equivalent of 40,000,000 tons of coal, whereas nearly 400,000,000 tons of coal goes into the production of steam power and carboelectric power.² The water power developed to date is around 10 per cent of that readily available; scarcely 3 per cent of the total open to development under elaborate arrangements for storage.³ (See fig. 15.)

The favorite explanation for this laggard growth on the side of water power ascribes the whole trouble, either directly or inferentially, to the handicaps imposed upon private initiative by the inadequacies of Federal legislation. The facts do not bear out such conclusion further than to accredit this factor with contributive importance. Federal permits are requisite to the development of 75 to 80 per cent of the potential water power of the country, the balance being accessible so far as Federal permits go. About 4 per cent of the restricted portion and about 25 per cent of the part outside Federal surveillance have been actually put to work. The discrepancy of 21 per cent between the two is impressive, but even granted that this is attributable wholly to Federal interference,

¹ See pages 134-138.

² The term *carboelectricity* is self-explanatory; it is used to cover electricity generated from the carbon fuels, such as coal. It stands in contrast to hydroelectricity, electricity generated from water power.

³ Estimates of this kind are provisional only, for the amounts of the "readily available" and "total" are not accurately known nor definite.

which is not the case,¹ it will be seen that the nondevelopment of three-quarters of the potential water power of the country remains to be accounted for on another basis. In other words, the quality of Federal legislation, even under sweeping concessions to its untoward effect, provides but a minor element in the complete explanation.²

The specific obstructions to the unfoldment of water power will be looked at later, but back of these instrumentalities is a fundamental economic setting which is essential to the view. The main features of this background are two in number. One is concerned with a relation between the power resources; the other, with the force of convention in respect to power usage.

In the first place, coal and oil have been so bountiful in this country that only the richest portions of these resources are worked; a

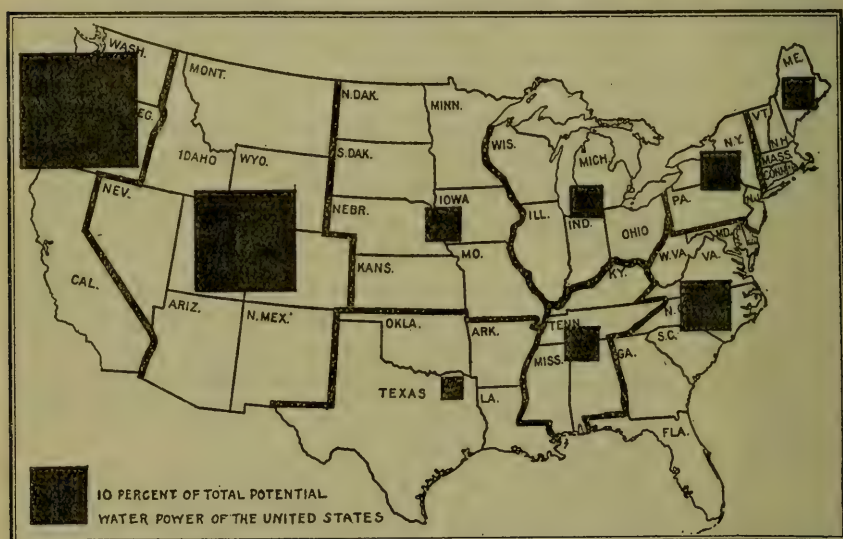


FIG. 14.—THE DISTRIBUTION OF THE WATER-POWER RESOURCES OF THE UNITED STATES.

project contemplating the development of a water-power site faces this situation.³ It is evident that the cream of the water-power re-

¹ The water-power rights subject to Federal jurisdiction are largely located in regions of the West remote from industrial centers where they are not currently wanted anyway.

² Of course, the whole default may be attributed to the Government's *lack of action*, but the total effect of ill-advised legislation, while significant, has been exaggerated.

³ Of course, the whole default may be attributed to the Government's *lack of action*, uneconomical basis of opportunism that for the time being a superabundance of coal and oil has been maintained on the market. It may sound as if one were making light of the facts to speak of there being an overproduction of coal and oil at a time when everyone has been meeting on every hand a shortage of these basic materials. Yet it is well within conservative figures to assert, even without reference to water-power potentialities, that this country has long produced more than double the amount of coal and oil really needed under proper arrangements; and, of necessity, the surplus has had to be consumed in the form of waste. Overproduction leads to waste; waste leads to overproduction; and so the circle goes on unbroken. With no pressing necessity for introducing economies in the use of coal and oil, there was still less of urgency to call the more basic economy of water power into play.

source has demonstrated its capacity to compete with the cream of the fuel resources, and it is a fair assumption that the balance is reasonably even in this area of rich values. But most of the cream, aside from that withheld by Federal restrictions and assiduously sought after by special interests with a taste for such matters, has been skimmed from water power, while it has not yet been exhausted from coal and oil; and the average of hydroelectric power, under present conditions, can not compete against the residuum of cream now being assiduously removed from the other two.¹ But the course of preferential skimming will tend to equal matters up, and a steady increase in the significance of the water-power resource is to be anticipated.

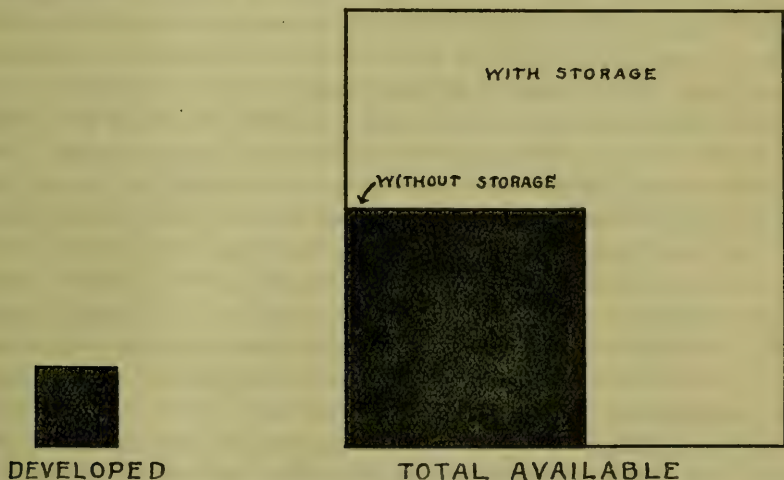


FIG. 15.—CHART SHOWING THE DEVELOPED WATER POWER OF THE UNITED STATES CONTRASTED WITH THE TOTAL RESOURCE.

In the second place, and viewed from the standpoint of the large consumer of power, the use of fuel is the established convention for covering the needs for power. Where steam power is wanted, fuel of course must be used. But even where electricity is re-

¹ It is evident, of course, that considerable coal and oil are being sacrificed for the sake of giving water power a better resource standing. This, in a national sense, is unfortunate; for the coal supply, while great, is not unlimited, and its needless use involves the loss of coal products, the true importance of which in a few years are bound to be recognized; while the petroleum reserve is already on the verge of exhaustion. The fuel resources are fixed in quantity and are in the nature of capital which does not draw interest; water power, on the other hand, may be compared to an annuity, the annual increments of which lapse if not currently used. Hence, as a concession to convenience and in the flush of resource wealth, this country has run into the economic impropriety of drawing upon its energy capital while neglectful of its energy annuity. While this, of course, will afford an unpleasant contemplation to the next generation and may even affect the younger members of the present, at the same time it is recognized that such a consideration has scant practical weight in favor of bettering the situation as standing now.

quired, fuel is usually the most convenient source. For purposes of generating electricity the primary power is ready at hand in the case of operations already established on a steam-power basis, while for the service of expanded or newly projected operations the simple expedient of enlarging or at most erecting a steam-power plant is all that is necessary. In either case the first cost is low, and the chief element in outlay is the expenditures under the heading of fuel purchases, which follow along steadily, but are distributed over the subsequent years of operation. The current proceeds from these operations are counted on to care for this train of expense; hence, from a pecuniary standpoint on the part of a given industrial activity, there is no occasion for advance effort in capitalization under this head beyond the amount called for in connection with the subordinate item of cost for the erection and equipment of a steam-power plant. In the case of hydroelectric development, on the contrary, the conditions are reversed, and the whole weight of emphasis falls at the outset on the initial cost of power-site development. The running cost of hydroelectric power consists mainly in the single item of interest money on the capital represented in the initial outlay. An analogous condition would obtain on the side of coal-generated electricity if a given enterprise were called upon to provide an adequately equipped coal mine in addition to the power plant itself. In the one instance, as matters now stand, the coal mines are already established in lavish numbers and do not enter into investment calculations; in the other, the power sites, with choice exceptions, still lie fallow and have yet to be developed if they are to be used. This is the situation facing any given industrial enterprise, however large, in respect to establishing its source of power. For the hydroelectric alternative to be chosen, it must present more than equal advantage. Indeed, it must be decidedly preferable, for projects in process of formulation or expansion are apt to find their capitalizing ability pretty fully exercised without taking on the development of any special source of power, whether in the nature of a coal mine or a water-power site. Hence, in the process of natural selection exerted by business enterprise, water power is usually set aside as presenting claims inferior to coal.

This holds true not merely for manufacturing projects but for purely electric-power projects as well. No exception is found even in these common instances of municipal electric-power supply, where the bulk of the consumption is on the basis of pay the price or do without. What is the use, in these cases, of undertaking the tremendous extra effort connected with developing a special water-power source, even granted an ultimate saving in cost? A public-

utilities commission would in all likelihood force a corresponding reduction in price, and all the effort would come to nothing really worth while, since these projects are in the nature of public-service corporations.¹ The public at large can be relied upon to pay any price conventionally established just so long as the actual cost of production is sufficiently high to prevent the rate from being too extortionate; hence, no one gains by lowering the cost of production—except the public, which goes, therefore, to no account. A special price may even be quoted to industrial users to discourage the larger interests from generating their own electric power, since they have a choice in this matter which the public does not enjoy. Thus the river that flows through the town has the beauty of its course unsullied by commercialism. Instead, a trolley park, with merry-go-rounds, dancing pavilions, loop-the-loops, and the like, occupy the power site. With its art and enterprise thus catered to, American municipal life in plentiful instances, not excepting that of the Capital city itself, is disposed to rest content.

Thus industrially and civically alike the electric-power situation is stagnant, caught in a backwater of convenience, with the course of progress blocked by the obstacles of initial cost. But it is not hydroelectricity alone which has its progress thus obstructed. Its case is conspicuous because the resource itself is largely cut off from employment and advertises the inadequacies of the situation broadcast over the landscape. The shortcomings with reference to carbon-electricity are not so obtrusive and hence not so notorious; they are not heralded openly by actual disuse, but are cloaked instead under conventional misapplication. Thus commonly as much as a fourth of the coal-fired power employed in centers of population has its energy applied in the form of electricity. Yet, with the rarest exceptions,² this energy is transported to the centers of use in the form of coal and there the electricity is generated in steam-power plants. Electric-power usage has merely been appended to the established structure of steam-power practice, with the result that the employment of power has been greatly facilitated, to the further aggravation of the broad problem of transportation. Thus far the very force that has the capacity to correct the transportation evil has merely served to accentuate it. By virtue of electricity, more power is con-

¹A designation not altogether clearly understood. It is sometimes construed as implying corporations serving the public instead of being served by the public. The former meaning is not justified by practice.

²The most significant exception is a power plant near Lansford, Pennsylvania, which was placed at the coal source for the express purpose of serving a distant patronage, its ultimate goal, indeed, being Philadelphia and New York. Of course, first and last, there are numerous steam-electric plants in the coal regions, but with very few exceptions they are present because of a local demand for electricity, not by virtue of the presence of coal; in the aggregate, therefore, they scarcely temper the transportation burden in the coal country itself and have no effect at all upon it outside.

sumed, more raw materials are required, more goods are produced, more coal is freighted.

The distributive generation of electric power was natural enough and the only practical procedure so long as the use of electricity was small. But that time has passed. Electricity is now a commodity in everyday use, with a large and steadily growing aggregate demand; to adhere to the original practice bespeaks obsolescence. Such escape as has been made from the confines of stagnation has been almost wholly in the direction of hydroelectricity. So, in spite of the great amount of talk and publicity that centers around the water-power issue, there is more evidence of basic progress on this score than may be found on the side of coal power. All that may be fairly said in dispraise of the progress of this country in respect to water-power is likewise true as regards coal power. In fact, this country does not face a water-power problem as such; the issue is more broadly a power problem, of which water power constitutes only one important segment.

Objection may arise at this point that a systematic generation of electricity in coal fields is prevented by technological difficulties in the way of long-distance transmission of power to the points of use. It is true that there are many open problems in long-distance service of this kind, but these are by no means insuperable; yet, granting them full weight and considering merely what has been already accomplished in connection with hydroelectric transmission, we find that transmission lines 100 miles in length are common, while those up to 250 miles in length are known and regarded as practical. If we accept say a 200-mile radius as a present standard, and consider the distribution of the coal fields of the country in relation to the centers of population, we find that circles may be drawn around centers of coal production which will embrace a considerable area and much of the industrial territory of the country. Thus on the basis of present technical attainments alone, with no allowance for improvements under way, a large share of the current power demand could be supplied directly over wires from the coal fields.

Such a change in practice would operate to the relief of transportation and on this score contribute a country-wide advantage. But it would also create special industrial opportunities which would fall only within the reaches of the transmission systems. Hence to plan a comprehensive development of the areas in proximity to coal fields would be to emphasize and accentuate the advantages of environment which are already proving hurtful to the economic growth of the country as a whole.¹ The economic gain that would come to outlying sections through the general betterment of transportation would

¹ See Nationalization of industrial opportunity, pages 134-138.

certainly be more than offset by the economic losses resulting from the increased disparity in power supply. There is no occasion, however, to confine attention to coal-field developments without regard to the distribution of water-power resources, which, as already noted, bulk largest in the regions lacking in coal. Rather than to single out the coal regions for favor, it would be preferable to take the opposite course, leaving the near-by sections to be served by freight-hauled coal and relieving the longer hauls by promoting the systematic development of outlying water-power sites, and thereby not only help transportation to better advantage but conserve the natural resources involved and diffuse industrial opportunity as well. But fortunately the two lines of action are not alternates. On the contrary, they enmesh in a singularly perfect manner and lead to a common end. In this light it is important to review more specifically the obstacles which have hindered water power and all but excluded coal power from assuming the complementary rôles to which they are admirably adapted by virtue of their natural dispositions.

Of the two, water power may be looked at first, because it is the more conspicuous in its failure and in extenuation offers reasons complicated by a greater scope of variety. For the most part these qualifications have already been examined, and, besides, to a great degree, they are either self-explanatory or, at least, have been given sufficient publicity of discussion to be more or less common property. Accordingly, in the interest of brevity, they may be listed with a few comments only rather than gone into at length.

1. *Adverse legislation.*—Here the situation has been clouded by various issues of Federal, State, and individual rights, covering not only the immediate subject of power but sundry other uses, such as stream navigation, likely to be interfered with. In view of these complications, legislation has characteristically been framed with an eye toward legalistic ends rather than in the direction of a genuinely constructive economic outcome.

2. *Public sentiment.*—There is a general feeling, natural enough in the strength of its hold, that in the beauty of the country's rivers, with their rapids and waterfalls, adheres a certain nobility of function whose grandeur is the common birthright of all. The surrender of this heritage to the interests of commercialized service is a line of conduct not likely to meet with public approval. Whatever of actual substance in the way of purpose is to be recognized in the fabric of legalism, as noted under the previous caption, has been contributed largely in response to this attitude of public sentiment. The attitude has unquestionable justification and must be reckoned with. Those on the one side who would have it ignored are as far wrong in the solution of the water-power issue as those who would give it unqualified heed. Yet the principle is universally recognized that the inter-

ests of beauty must give place to pressing needs of utility. This consideration alone would not give rise to disfavor in regard to water-power development. The source of disapprobation lies in the lack of vivid appreciation as to the matter of need, coupled with the attendant imputation of surrender to vested interests. Accordingly the water-power situation can not be satisfactorily cleared up until the need for the systematic development of this resource is firmly established; until freight congestions, fireless homes, foodstuff costs, and other intimately personal issues are seen to be genuinely involved; until the opportunity for the restrictive furtherance of special interests, financial or sectional, has been eliminated. Until these conditions have been met, attempts to promote the development of our water-power resources are bound to result in ineffectual compromises.

3. *Cost.*—A hydroelectric station, once established, is largely self-contained and automatic in operation. There are no periodic items of cost for fuel, for its freightage, haulage, handling, and the like, such as associate themselves with the operation of a steam-power plant. So, apart from such incidentals as administration, insurance, taxes, and depreciation, which together bulk small, practically the whole burden of gross operating expense is that assumed at the outset in the guise of initial cost and perpetuated in the form of interest money.¹

Thus the cost of money, displaying itself in bond interest, is the determining factor in the cost of hydroelectric power precisely as the price of fuel, with its accompaniment of expense, determines the cost of steam power. The cost of money in this country, on a strictly commercial basis, is high. The prevailing rate of interest demanded of water-power developments is around 7 or 8 per cent, which, with discounts taken into consideration, normally means a demand amounting to 9 or 10 per cent on the working proposition. Estimate after estimate the country over has gone to show that only the

¹ A unit analysis of the gross operating expenses of a typical steam-electric and hydroelectric station of the same capacity (21,000 horsepower; annual load factor, 50 per cent; coal, at \$3.25 per ton delivered) is given as follows by Gano Dunn, The water-power situation including its financial aspects, *Proc. Amer. Inst. Electr. Eng.*, May, 1916, p. 585:

	Steam station (per cent of total gross operating expenses).	Hydroelectric station (per cent of total gross operating expenses).
Administration.....	4.0	4.0
Ordinary operating expenses (except coal).....	10.6	4.8
Coal.....	48.9	
Taxes and Insurance.....	6.7	2.8
Depreciation.....	10.8	11.0
Bond interest.....	19.0	77.4
Total.....	100.0	100.0

water-power site especially favored by natural advantage is susceptible to development under these conditions in competition with the prevailing cost of steam power. These favored examples also frequently provide a bone of contention over which conflicting interests raise a great to do, tending to create the impression that the water-power resources of the country constitute a tremendous asset whose possibilities are being arbitrarily withheld from their normal course of unfoldment. Nothing could be much further from the truth. With the exception of the few conspicuous instances that serve as a stimulus in keeping the question alive, no particular significance attaches to the country's undeveloped water power under existing conditions of finance, or will, until either these conditions have been lived down or steps have been taken to better them. The former represents a tendency which left to itself is not likely to yield anything of consequence for years to come. Nor is there any room for hope in technological advance. The issue of cost is a matter which, like the legal and sentimental obstacles just outlined, must be overcome, and the only way in sight lies through arrangements which will impart a degree of stability to water-power securities such that they will receive the benefit of a reduced rate of interest. This phase of the subject will receive further attention later on.

Thus the influences holding back water-power development are of a threefold order. These do not operate separately, but in conjunction with one another. Water-power development stands in need of special consideration; instead, it meets with special opposition. There is none to work in its behalf except those with special objects in view, and the recognition of this quality in their efforts has gone to establish opposition. The contention in this wise has grown to be organized on both sides, with each alike oblivious to the real community of interests involved and legislative action caught fast in an entanglement of compromise. In all three respects the situation is in a deadlock and the likeliest chance of a break toward progress lies in the entry of a new standard in the field, a standard under which the rights and best interests of all concerned can have the assurance of fitting recognition.

The carboelectric issue, on the other hand, is far less advanced and correspondingly less complicated. It has scarcely progressed beyond the general setting of inertia which characterizes the failure to locate power stations at the source of fuel supply and still determines their establishment distributively at the points of use. There have been no special interests involved to stimulate any particular activity otherwise; there has in consequence arisen no basis for the provocation of organized opposition or legal byplay. The hydroelectric issue has been seen to stand in need of a new standard; the issue of carboelectricity has not even been popularly recog-

nized. Ordinarily, under such conditions, sporadic activities appear over the even surface of apathy as precursors to an organized effort to follow. In this case there has been an obstacle to check such sporadic beginnings. It is the obstacle of initial cost expressing itself in the matter of electric transmission lines. In meeting this aspect of the situation we come face to face with the third element of our major theme of discussion—the facilities best suited to advantageous transportation.

FACILITIES OF TRANSPORTATION AS APPLIED TO POWER.

We have seen from our discussion thus far that full utilization of the energy materials in distributive use involves the constructive application of the principle of multiple production, and that the advance elimination of weight is concerned with the generation of electric power in centralized relationship to coal fields and water-power sites.¹ The nature of these issues and the problem they afford have been explored, and it now remains to trace the issue concerned with the provision of adequate facilities for the transportation of energy in concentrated form.

Energy is practically the only natural resource product susceptible of concentration which is shipped broadcast in the crude condition. The dictates of demand, it is true, still call for a large proportion of the supply in the crude state, and to this extent concentration in advance is obviously impracticable.² But the order of requirement is changing rapidly, and even now over one-fourth of the call is for the concentrated product—electricity. Yet, as we have seen, there has been no progressive change in practice to correspond. It is as if our gold supply were shipped in the crude state of its native occurrence for concentration at the market centers instead of at the mine; for whereas the degree of material concentration effected on behalf of gold is considerably over 99 per cent, the attainment possible on the side of energy is a full 100 per cent. There is just one important difference between the two instances. Refined gold is adapted to haulage by the conventional means of transportation at hand, fully as much so, indeed, as the ore from which it is derived. But refined energy is not. It can not be loaded in freight cars or done up in express packages. The alternatives lie in providing special facilities of transportation or else hauling the crude material in all its excess bulk for concentration at the points of use, and the

¹ It is only as applied to organized transportation that the issues of advance concentration and multiple production are strictly complementary. The recovery of by-products is just as feasible and desirable in connection with carboelectric superpower stations centralized in respect to coal sources as it is in connection with any set of operations centralized with reference to consumptive demand, as, for example, in the case of gas manufacture.

² Except in so far, of course, as a change in the supply would modify the demand.

choice in practice has uniformly fallen in favor of the second procedure.

The reason for this uniformity is obvious. It is cheaper for the user of energy to rely upon the transportation facilities already at hand, employing them in the movement of the crude bulky material, than to provide himself with special facilities for the transmission of the refined electric derivative. But it does not follow, to be sure, that because the procedure so uniformly followed is individually cheaper, this course is economically preferable. In the absence of railway facilities, for example, it would be decidedly cheaper for the individual consumer to haul his coal from the nearest mine by truck than to build a railway line for the purpose. Yet no one would think of arguing in this case that reliance upon truck haulage is preferable to the opportunities that would be afforded by railway transportation. The issue between electric transmission and railway haulage is precisely similar.

The provision of special facilities of transportation finds its justification in the magnitude of the service to be rendered. Were the item of haulage under view small in size or restricted in locality the whole matter need not come up as a broad problem. But the haulage of power in material form amounts to nearly a half billion tons and covers the country. There is no default, then, on the side of magnitude. Special facilities, too, have been provided for oil, the power material next in importance to coal. To serve the ends of this large resource a network of pipe lines, thousands of miles in aggregate length, is spread over half the country. In this case, however, crude oil is not in the nature of a general utility, but serves a specialized industrial demand centered in refineries. In consequence, pipe-line transportation found its creation and nourishment at the hands of the large private interests at stake. For electric power, on the contrary, there was no such activating interest. Though bulking large, it enjoyed a diverging distributive use quite the opposite of the convergent refinery consumption of crude oil. Moreover, the railroads were already established in coal fields when electricity came on the scene; their presence, therefore, offered scant encouragement to the growth of a more modern type of common carrier. On the contrary, it may be surmised that the whole matter may have been arbitrarily held back by the pecuniary disadvantage that would accrue to the established undertaking in event of change. Indeed, it may well be that this consideration has not been without weight in retarding the electrification of the railway lines themselves. A given railroad, under conditions of active competition, could scarcely be expected to take the lead in giving up such a lucrative item as the transportation of coal. It thus appears

that such interests as already occupied the field were inclined to oppose the provision of special facilities for the transportation of energy, while in respect to oil the interests concerned in advancing its transportation were sufficiently strong and organized to overcome the factors inhibiting the establishment of the modern pipe line. Hence the energy needs of the country are now served by two carrier systems instead of three.

A special type of transportation equipment in the way of electrical transmission lines is urgently needed to serve the energy requirements of this country, but these special facilities may be advantageously established only on the basis of a common carrier. In close analogy to the railroads, though in contradistinction to oil pipe lines, the service to be rendered is strictly distributive and of a public-service order; hence competition here is out of place to precisely the extent that it is inexpedient in the case of the railways. The railroads of this country wrought havoc with industrial life until the element of special-interest preference was eliminated and the whole system was placed on a common-carrier, public-utility basis. We may profit in this matter by that experience, and arrange to skip the period of adjustment that proved so costly and disastrous in connection with railway development. The railroads, therefore, provide a warning example from which may be determined the status that should be accorded the new development. Hauling coal is a problem of transportation; hauling energy in the form of electricity involves the same range of principles but requires merely a different set of physical means. In point of fact, the whole advancement contemplated is but a further refinement in transportation equipment, just as the modern steel gondola¹ is a refinement of the old-fashioned coal car.

The railroads themselves have a prime interest in this matter of establishing more facile means for the transportation of energy. Not only are they the chief haulers of energy in bulky form, but they likewise constitute the chief single consumer of this material energy which burdens their lines. The railroads burn approximately a fourth of all the coal produced in this country,² this item alone representing at least a tenth of their total operating expense.³ Thus an improvement in energy transportation would not only relieve the railways from a needless burden of bulk haulage, but would at the

¹A self-dumping car now in common use for hauling coal.

²In 1915 the railways of the country used 24 per cent of the total output, or 28 per cent of the bituminous production (C. E. Leshner, Coal, Mineral Resources of the United States for 1915, United States Geological Survey, pt. 2, 1917, p. 473). This has nothing to say of the fact that about one-eighth of the petroleum output is consumed by railways.

³A determination of 11.05 per cent is given as an average of all the railroads in the United States having operating revenues greater than \$100,000 in the year, by L. B. Stillwell, Relation of water power to transportation, Proc. Amer. Inst. Electr. Eng., May, 1916, p. 562.

same time benefit otherwise their operations by giving an impetus to railway electrification, with attendant gain in freight movements by nature of the greater freight capacity accruing to electrified systems.¹ Thus, on every count, the matter resolves itself into an inseparable part of the transportation problem, and from this coalescence there is no escape.²

CORRELATION OF WATER POWER AND COAL POWER.

Bringing together the two issues of water power and coal power, which we have followed thus far in parallel considerations, we find that the causes which have retarded the development of hydro-electricity and prevented the establishment of carboelectric power stations at coal mines are broadly similar. In the case of water power, the failure is traceable to (a) initial cost and (b) a dead-locked issue between public and private interests; while, with coal, the element of initial cost has been almost equally effective, with a lack of interest,³ instead of discordant interests, acting as the contributory factor. The provision of suitable transportation will clear up the two retarding influences in both cases.

In the first place, the establishment of a common-carrier system of electric transmission lines on a public utility basis will nearly halve the interest rate now demanded of projects having to do with electrical developments. We have for this assurance the example of the railways themselves, which have long been accustomed to procure capital at rates of 5 to 6 per cent. The system under view could be given more stability than the railways have formerly en-

¹ The increase in freight capacity that accrues from electrification, with its accessory automatic devices that permit an almost solid stream of freight cars, is startlingly great in view of freight congestions under present arrangements. With proper terminal facilities and electrification, it is safe to say that the freight capacity of a system could be multiplied by a considerable figure. It has been recently estimated, for example that inland transportation in England attains a capacity efficiency of scarcely 10 per cent. It has frequently been noticed in the United States as to the anomaly of hauling coal halfway across the continent to lift a train across the Continental Divide, when the topography of the divide is ready to provide for this purpose hydroelectric energy, which itself is susceptible to partial recovery on the down slope by means of regenerative braking. In this connection, the pioneer work of the Chicago, Milwaukee & St. Paul Railway is deserving of the highest commendation for its constructive significance.

² It is commonly recognized that one of the weakest features in the industrial development of the United States is the overaccentuated responsibility now falling upon the railways; any measure tending to lighten this weight obviously strikes at the roots of a very fundamental and important issue. While the consideration may be a gratuitous digression in this place, a plan for adequate inland transportation in this country is conceived to embrace (a) airplane service for special mail and for passengers restricted in time; (b) motor-truck service for short-haul freight and for the service of farming districts in coordination with parcel-post deliveries; (c) railway service for normal freight and passenger accommodations; (d) trunk-line, deep waterway haulage for slow-moving and bulky freight; and (e) transmission lines for the delivery of electrical energy from the coal fields and water-power sites.

³ Such private interests as might have had a concern in the matter (as the railways) were rather inclined to cast their influence on the side of inaction in this respect; while the public interest, as usual, had no eyes with which to see their concern; in result, a state of outward apathy surrounded the issue.

joyed, to the gain, perhaps, of even better interest rates than may be calculated from the unqualified analogy. Not only would this stability be inherent in the transmission line development itself, but would reflect a similar measure of soundness upon the projects concerned with the development of power sites and the establishment of power plants, so that the field of power operations in its entirety would benefit. The recognition of public backing would transfer the whole matter from the type of investment sponsored by the professional promotor to the realm of securities represented by bonds of a substantial and conservative standing. And since the cost of money is the major expense attached to the developments, the reduction of this factor would reflect in increased proportion in the lowered price of electric power.¹

In the second place, a special common-carrier system under public oversight would serve to give the proper temper to the apprehension of the public in respect to surrendering what is now conceived to be its natural rights, thus breaking the deadlocked issue that has so long contributed to the sluggishness of hydro-electric developments; while the apathy surrounding the matter of coal-field generation of electric power would be replaced by conditions making for the profitable establishment of this activity. The public, seeing its interests properly safeguarded, can be counted on for sympathetic support of the movement; while industrial interests in general, being in the business of manufacturing commodities rather than energy, will find it natural to favor any action that would facilitate the supply of energy—an accessory to their operations—just as they are keenly interested in any constructive measures that would be likely to ease off the labor problem.

The experience of this country has shown that the conduct of the common-carrier systems must be subject to public oversight. At the same time, it has been amply demonstrated that, for the sake of safeguarding private initiative and business enterprise, this oversight should be called into play as slightly as conditions permit.² Applying these concepts to the proposition in hand, we reach the conclusion that while it is necessary that a system of electric transmission lines should be of a common-carrier, public-utility order,

¹ It should be mentioned that in many instances the development of water-power sites involves the provision of facilities for navigation and irrigation. These attendant activities would be in the nature of by-products, so to speak, over the gain to be derived on the score of power, and as such they should weigh in outlay calculations as joint sharers in the expense apportionment. The provision of a lower money cost for water-power development, therefore, would reflect advantages over a wider scope than is embraced even in the broad item of power usage.

² While there can be, of course, no universal agreement to premises of this kind, these two conditions are believed to represent fairly the common sense of the country in this matter. They certainly involve no violent assumptions, for both for some time have been guiding influences in the destiny of the Nation.

for which the railways provide a pattern;¹ the realm of power production offers great leeway for the upgrowth of coordinated, but separately constituted activities, thus stimulating initiative and encouraging business enterprise far beyond their present attainments in this field. In this connection, it is worthy of emphasis that such restrictions as may be inherently necessary in correlating the whole fringe of attendant activities with the central enterprise will be overwhelmingly offset by the tremendous opportunities created by the unfoldment.

This type of development will place water power and coal on an equal footing. In regions where only one is present, that, of course, will alone produce. But in regions where both are on hand, the one rendering the cheaper service will come into play through a process of natural, unhampered selection. Thus the common carrier will coordinate the two resources, so long estranged, and lead to their complementary and balanced development. Adequate transportation has always been necessary to the development of resources; it is a trite commonplace that no region, however rich, can become of consequence until served by proper carriage. This is no less true with energy. Given suitable transportation, our energy supply is assured.²

The final status of a common-carrier system for the transmission of energy can not be determined at this moment. The entire problem of transportation is in course of flux, and the special issue of power must be cast into the cauldron in which the railway matter is boiling. As the railways emerge, so should power. But with no inclination toward voicing a decision in the matter, it may be anticipated that a special transportation service for power, to fulfill its proper function, will have to be either (1) an integrated activity, privately financed, but under public oversight on the basis of a common carrier, and comparable to a railway company; or (2) if still closer Federal oversight be desirable, a close corporation, in which the Government holds the stock, bearing some analogy to the

¹ Owing to the relative shortness of transmission radius (up to about 200 miles under present practice), conditions might arise in certain localities in which the authority vested in the Federal Government under the head of interstate commerce might prove more restricted than in the case of the railways. These and similar difficulties will no doubt arise, and objections to the whole conception may be raised on this score, but technical niceties and equivocations are being cast aside right and left in response to the claims of progress, and in this respect nothing of an unsurmountable nature can be discerned ahead.

² Taking a broad view ahead, we are confronted with the fact that the whole forward sweep of electrical development is dependent upon a supply of copper, or some such metal of ready conductivity. The copper supply of the world has come under close observation during the course of the war and there has resulted no special confidence in the bountifulness of supply for the future. As is well known, copper mining has already been reduced to the expedient of working a lean type of disseminated deposit by large-scale methods of operation, and a large part of the world's output is so derived. In view of the importance of the property of conductivity, the whole future of transportation would seem here to enmesh with mineral resource efficiency in respect to copper and with electrochemical advance in respect to developing supplies of other conductors.

activities now being carried on in behalf of the country by the Food Administration and the Emergency Fleet Corporation.

But whatever the outcome of the railway issue—or, more broadly, the transportation issue, from which the power problem is inseparable—this country need not wait upon the eventuality before taking action. Just as the railroads are not idle during the period pending their final disposition, so the matter of energy transmission should not be held in abeyance until the question of control is settled. On the contrary, the establishment of such a project would require a preliminary period of planning and investigation, including a survey of the coal and water-power resources of the country with reference to the demand for power, and there is no apparent reason why this initial activity could not be engaged in at once. In view of the importance of the issue, this is not a matter to be referred to one side as an incidental piece of work, but belongs properly as a feature in the emergency activities of the day.

NATIONALIZATION OF INDUSTRIAL OPPORTUNITY.

Power and raw materials constitute the foundations of industry. Capital, labor, markets, and other elements enter into the structure, but they do not lie at the base. Neither power resources nor raw materials are uniformly available; both tend to be provincial in occurrence; but since industrial power is dominantly drawn from coal, while raw materials are derived from a thousand sources of organic and mineral origin, the aggregate availability is far more restricted in the case of coal. In other words, any given section of the country is almost invariably provided with raw material of some kind, while under the present régime only those sections contiguous to rich coal fields are amply provided with power.¹ The geographical and political consequences of the localized occurrence of coal and of concentrated types of raw materials² are obvious and well known. The inequalities of opportunity conditioned by these matters have always been bones of contention, from the aboriginal strife over deposits of salt and flint down to the action which resulted in the conquest of an iron-bearing province and contributed prominently to the recent epoch-making conflict.

Discord from this source is as old as human history and nations have evolved with the placement of their boundaries strongly influenced by concentrations of resource opportunity. The North American Continent, however, provides a notable exception to the rule. Its vast area was explored and appropriated before its resource potentialities were recognized, and hence its various sections came

¹ On the Pacific slope and in the Southwest oil takes the place of coal in this respect.

² The organic raw materials are less significant in this respect than mineral resources, since the former are reproducible and not so exclusively focussed at specific points.

to be unified into a few nationalities on the strength of social bonds, which, with one or two exceptions, have nowhere been dissevered by subsequent economic influences. Thus the United States is a nation of many parts bound together by social unity, but separated by a divergence of economic interests. The development of natural resources has given rise to a marked differentiation in the quality of opportunity opening up to the different sections, while the boundaries of the economic provinces set up in this wise are further emphasized by a general conformity to topographic features disfavoring intercommunication. Thus this country is displaying a steady drift toward economic variation and specialization among its members.

But national well-being is dependent upon economic unity no less than upon social unity. The Civil War, in the last analysis, had its origin in discordant economic sectionalism. A military expression of domestic discord is outgrown, but civil strife is not the sole misfortune that may arise from cross interests. Without economic unity a definite economic policy is nationally unattainable. And with no formulated economic policy, one of the two prime functions of government is reduced to the rank of partisanship, and industry is left to the paralyzing influence of uncertainty as regards the future of prospective operations. Thus far the divergent economic interests of the various sections of the country have not permitted the establishment of a constructive economic policy satisfactory to the Nation as a whole.¹

Elements too numerous to specify enter into this sectionalism of interest, but the most conspicuous contributor to the outcome is the presence or absence of resources productive of mechanical energy. Given a region endowed with an ample supply of coal, for example, and all the other elements of industrial activity gather in the manner of an accretionary growth. Even the crudest raw materials tend to be drawn to the sources of energy in greater measure than is found true of the reverse relation. Other attractions, to be sure, such as labor supply, markets, and transportation facilities register strong claims tending to diffuse and spread the focus of development, but industrial concentration never migrates beyond the convenient reach of power, which therefore sets the outside bounds to industrial range. Thus certain naturally favored sections of the country have come to have a predominant interest in manufacture, while other sections in the rôle of producers and consumers for the manufacturing areas are led to react to motives and economic interests foreign and even

¹ The lack of a constructive economic policy in the United States is more than a negative matter. The deficiency is responsible for such items as a nitrogen problem, a potash problem, a manganese problem, and others, which war conditions made apparent—to cite merely a few examples in the realm of mineral resources.

antagonistic to those of manufacture. Where such a situation is permitted to develop in accentuated form, an economic policy satisfactory to the two extremes would appear to involve a type of concord foreign to human nature.

The influence of energy resources in an unfavorable and favorable direction may be illustrated by two examples; one drawn from conditions obtaining in New England, and the other taken from recent industrial developments in the South Atlantic States.

In New England the foundations of industrialism were laid during the régime of water power. With the advent of steam power the abundance of coal available to the Middle Atlantic States set up a strong counter attraction which entailed a steady migration of industry away from the New England section, since this area contains no coal, and is marked by physiographic conditions which provide inadequate gateways for rail transportation and necessitate a roundabout rail-to-water-to-rail service exposed to all manner of exigency.¹ Still, with the advantages of its early start, New England maintained a powerful asset in the form of skilled labor, and the weight of this factor has overbalanced the lack of an adequate power supply in those special forms of industry involving specialized workmanship. These, therefore, still prevail and reflect the peculiar color of the situation. But in the newer industrial sections elsewhere skill of workmanship is in process of development, and is steadily lessening the attraction of an advantage which transiently favors New England. In time this factor will be practically neutralized, and with continued inequality of power supply New England will see its industrial life narrowing under the cumulative weight of a growing handicap. This is an example, then, of how a natural power supply may create a development in one part of the country at the expense of another section, a circumstance not making for unity of interest.

The South Atlantic area resembles New England in respect to power resources; coal must be hauled in from a distance and water power is fairly abundant. But whereas the industrialism of New England is the oldest in the country, that of the South is among the youngest. Here, indeed, the growth of industry has been largely a matter of the past 15 or 20 years, subsequent, therefore, to the introduction of electricity as a motive force. In consequence much of the upgrowth is built upon the use of hydroelectric power, and tends to be distributive—that is to say, *natural*—instead of a forced growth in proximity to localized coal belts. Coming into action late the industrialism of the South, unhampered by tradition and unencumbered by obsolescent power establishments, took over the practice best suited to its needs. Thus while the Northeastern States form an

¹ The weakness of New England in this respect was conspicuously brought out during the war.

illustration of centralized industry, establishing itself first in New England and migrating later to the Central Atlantic States and thence westward, the South displays a regional deployment of industry, nowhere intensely focussed, but spread, on the contrary, in diluted form over a large area. The contrast is suggestive; for permanence, for national well-being, for the common good, it would appear that a balanced economic life in which each section manufactures, in large measure, its own products is preferable to a highly intensified manufacture setting up its own interests in opposition to the more extensive producing areas. The South presents an example of power supply disposed to create a normal development from within, with minimum detraction from the opportunities peculiar to other sections.¹

These are but two illustrations of fields in which power supply is a strong economic force. Each section of the country, in point of fact, has its own peculiar reflex to this matter. The Pacific coast, for instance, has a specialized and acute power problem to meet; there the rich oil fields of California launched a period of industrialism which this source of power can not much longer sustain. The industrial life of this whole section is threatened by the impending decline of its oil fields. Similarly with the Southwest. The power influence, then, is country-wide—here throttling established industry; there leading to overbalanced growth; elsewhere retarding needed developments; rarely promoting well-rounded economic growth; on the whole, making for divergence of economic interest.

This situation, undesirable as it stands, is bound to grow worse if matters are left to untrammelled evolution. Human labor is mobile; it is becoming standardized, even nationalized; cheap labor locally restricted is disappearing. Thus the factor of labor supply is losing its distributive effect upon industry. In consequence, the presence of mechanical labor (power) will become an even greater centralizing force than heretofore; manufacturing districts will tend to be more strikingly developed than ever. The natural tendency, in short, will be toward the building up of centralized industry enjoying monopolistic advantages of power supply, a condition in itself constituting a restraint in respect to the adequate unfoldment of other industries beyond the reach of the favored source.

Such an interplay of economic forces is complex and proclivities can not be expected to travel far undeflected by new conditions, but whatever the uncertainties of the matter, the power situation merits attention in respect to its present untoward bearing on economic policy. If a constructive economic policy is desirable for this country, and if the conclusion is valid that the power supply represents

¹ The Government project at Muscle Shoals may prove to be a disturbing factor in the present distributive unfoldment of southern industry.

a force now working against the unification of economic purpose into a national policy, but capable of direction toward such an outcome, the whole matter becomes a fundamental issue which may not be ignored. In short, a coordinated and balanced development of the coal and water-power resources of the country, which will follow from the establishment of an adequate common-carrier system of transmission lines, will serve to equalize industrial opportunity and therefore to unify the economic interests of the country so that a constructive economic policy agreeable to all sections may win country-wide support.¹

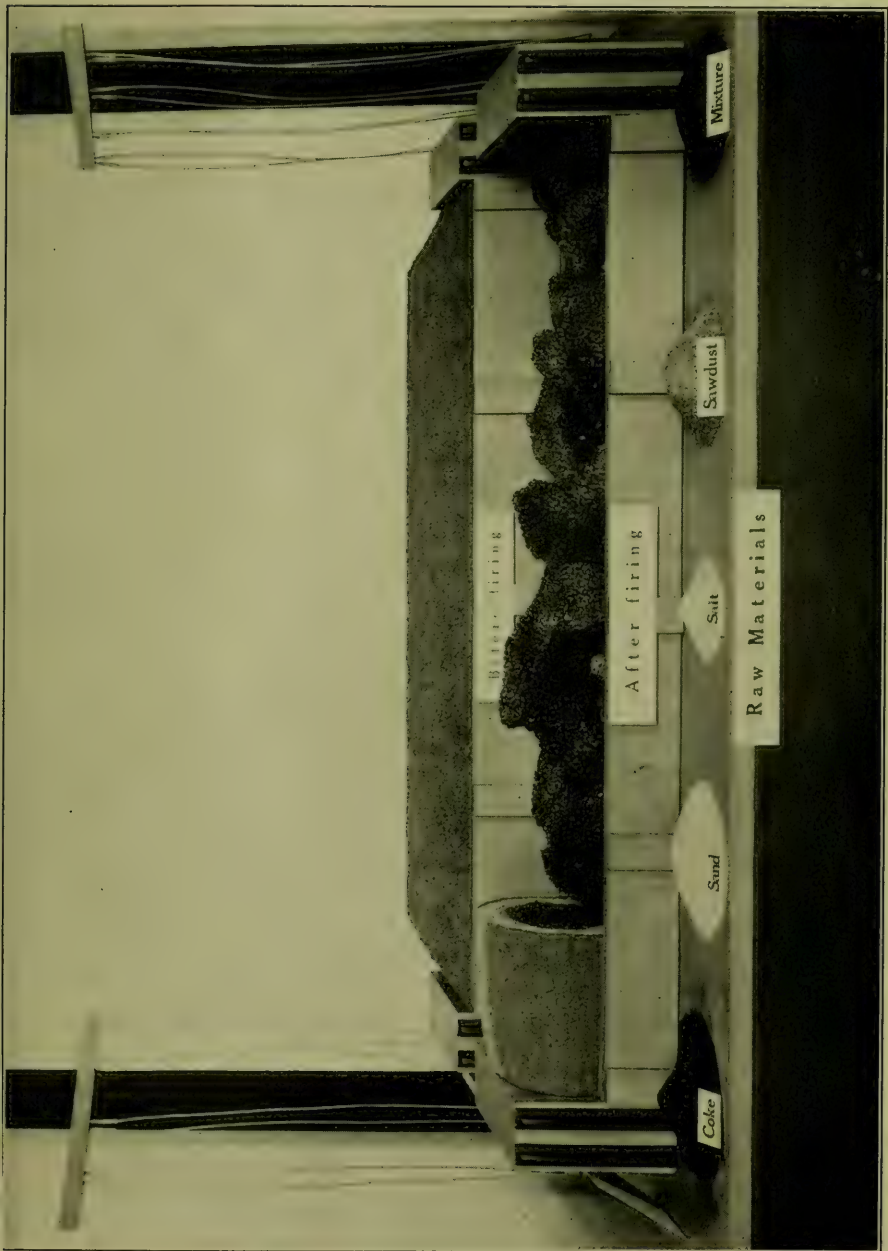
But in addition to its bearing upon national policy, a distribution of power advantages will make for an indirect but very significant gain in the matter of transportation; for industry may then strike a more perfect balance between the location of raw-material sources and markets. As the matter now stands, the adjustment is a compromise between three main factors, of which the position of the fuel source is dominant, and the industrial centralization resulting is in considerable measure responsible for the "bottle-neck" restrictions in the transportation layout of this country—a pattern that has become a conspicuous source of transportation weakness during the past year. The nationalization of industrial opportunity through equalized power supply will permit the upgrowth of new industrial activities in positions which will impose a lessened relative burden upon the railways and diffuse the intensification of responsibility that is now bearing with growing force upon the necklike restrictions in the neighborhood of present industrial centers.²

ENLARGEMENT OF INDUSTRIAL OPPORTUNITY.

We have seen that power supply constitutes a strong attractive force, leading under natural conditions to marked industrial concentrations in certain parts of the country. The unfavorable bearing of this circumstance upon the attainment of a national economic policy is noteworthy and constitutes an argument for directing the sectionalizing force of power supply into more distributive channels than it seeks of its own accord. The most effective means toward a better balanced industrial growth in this respect is afforded by electricity, which lends itself to generation at fixed points in coal regions and at water-power sites, and to transmission thence to adjacent areas in such manner that, if the growth as a whole be properly shaped, a

¹ In a sense we come here upon one of those circles which so often block progress; a constructive economic policy is essential to a proper development of the power supply; such a policy is hindered from coming into existence by the present haphazard status of the power supply with its contribution to economic sectionalism.

² The gains in inland waterway transportation and in western irrigation that would come as incidentals in a broad development should not be overlooked.



AN ELECTROCHEMICAL INDUSTRY. THE MANUFACTURE OF CARBORUNDUM, A SYNTHETIC ABRASIVE.

Photograph of a model in the Division of Mineral Technology, United States National Museum.

much larger portion of the country may be served with power on terms of equality than is now the case. Thus can power be turned away, in considerable measure, from its present dangerous facility in accentuating diversity of economic interest and made to contribute to the nationalization of industrial opportunity.

But just as coal contains valuable commodities as well as stored-up energy, so electricity is not merely a convenient form of power, but is a new and profoundly important chemical agent as well. In this sense electricity represents a fresh industrial factor which is just beginning to come into play and bids fair to make for itself a master range of activity. Electricity, then, is not only capable of distributing industrial opportunity; it is competent at the same time of infinitely enlarging the scope of industrialism. The opportunity in this direction is so significant and has so recently become apparent that the field merits a close view in connection with the whole matter of power supply.

This field of special electrical service, in contradistinction to the application of electric energy as a motive force, is covered by the term "electrochemistry," which is the art of applying electrical energy to the furtherance of chemical operations. The aptness of electricity for this purpose has proved so great that in scarcely more than a decade there has developed a large number of electrochemical industries, in addition to a growing range of superior adaptations in established industries and in the realm of metallurgy, with the setting up of a new branch of the latter known as electrometallurgy. Thus electrochemistry has not only facilitated ordinary industrial activities in many directions; it has opened an unbounded territory never before traversed by industry.

The facility of electricity in this new realm is due to its capacity for generating heat under conditions open to exact control, over high temperatures not attainable by fuel combustion, and in absence of gases, together with the exertion of a chemical force of decomposition independently or in conjunction with the heating effect. Thus electrochemistry operates through its dissociating effect upon solutions and melts, a process technically called "electrolysis"; through discharges in gases; and by means of electric furnaces. Upon these operations depend the manufacture of alkalis, chlorine, atmospheric nitrogen, graphite, artificial abrasives, and calcium carbide; the production of aluminum and many of the steel-hardening metals; and the refining of gold, silver, and copper—to mention merely the most conspicuous attainments of the electrochemical art.

The achievements of electrochemistry to date are to be credited mainly to the region around Niagara Falls and to foreign countries, especially the latter. Elsewhere in the United States there are relatively few electrochemical activities. Such as have been established are

in the vicinity of choice water-power sites or, as in the case of recent atmospheric nitrogen fixation plants, subsidized by the Government. But, by and large, electrochemical industries are grossly undeveloped in this country, relative both to their intrinsic importance and to their upgrowth abroad; and while a considerable expansion has resulted under the stimulus of war prices, the course of progress is under the handicap of power costs running far in excess of what is offered in Canada and abroad. Since power is a large item of expense in most electrochemical activities, its high cost in the United States is not only preventing development, except along specialized lines of high-value small-bulk products, but is causing an emigration and settlement of such industries in other countries offering a more genial atmosphere of power costs. Not only this, but the tide of emigration is actually affecting the industries already established at Niagara Falls. On the whole, then, counting off war-time exuberance, our electrochemical industries while growing in an absolute sense are relatively stationary, if not actually retrograding. That is to say, our electrochemical needs are growing faster than our electrochemical industries, which means that an increasing dependence upon foreign developments is under way.

If the high cost of electric power in the United States is blocking adequate electrochemical developments, we should take time to examine the scope of the fields that are being retarded by this circumstance. Such a retardation, of course, is difficult to visualize, for its most important area consists of what has not been accomplished; or, rather, of the margin between current and possible attainments, so far as determined by conditions of power supply. Yet the prospect can be swept, even though we may turn aside before coming up with it.

In the realm of metallurgy, electricity opens to use a number of metals not commercially extractable from their ores on any other terms. The most conspicuous example is aluminum, which was a chemical curiosity until thus made available; but such metals and elements as magnesium, calcium, sodium, potassium, cerium, and silicon are also coming into prominence, although the applications of these newer additions are still in their infancy. It is not unworthy of note, although the bearing of the fact may not become conspicuous for many years, that electrometallurgy offers a means for turning the more common and leaner mineral materials to account when the exhaustion of the rather limited and rich concentrations heretofore exploited shall have been accomplished.¹ For the manufacture of a

¹ In this connection it may be recalled that the valuable elements available solely by electrochemical means constitute nearly half of the earth's crust, while such useful elements as copper, lead, zinc, silver, nickel, tin, and the like, available before the advent of electricity, comprise together less than 1 per cent. This takes no account of the 4½ per cent of iron present, but electro-smelting may come to represent the only means for handling the lean occurrences of this metal.

great number of metallic alloys, such as ferromanganese, ferrochromium, ferrotungsten, and others needed to give to steel the various special properties demanded by its many applications, electric power is essential, while for the production of iron and steel the use of electricity is finding a growing application. Indeed, many "metallurgists in active practice in the United States are convinced that the time is rapidly approaching when all steel made will be passed through the electric furnace to receive its final refining and its finishing touches. We may safely look forward to the establishment of not only hundreds but possibly thousands of electric steel furnaces."¹ In the metallurgy of copper, zinc, and tin electricity is coming into play, while in the refining of metals it is affording the means for recovering many constituents formerly going to waste, in addition to producing products of such purity as to open up new uses not previously enjoyed.² The United States is the greatest producer of metals in the world, and proper electrical-power development will give a great impetus to the advancement of the mineral industries.

No problem is more fundamental to any country than the matter of food supply, and electrochemistry has a very direct bearing in this respect through its promise of lending assistance in producing fertilizers. Of the three important fertilizing materials—nitrogen, phosphorus, and potassium—nitrogen may be drawn from the atmosphere by the expenditure of electrical energy; cheap electrical power offers an immediate means for doing away with the cumbersome method of converting phosphate rock into acid phosphate, with its consequent burden upon transportation and upon sulphuric acid manufacture;³ while the locked-up stores of potash held in unlimited amount in widespread areas of silicate rocks must eventually be

¹ J. W. Richards, *Electric furnace metallurgy*, Proc. Second Pan American Scientific Congress, vol. 7, 1917, p. 265.

² The United States Bureau of Mines has recently announced the perfection of an electric smelting furnace that may be revolutionary in the making of brass. The use of this furnace will replace costly crucibles of imported clay and graphite and reduce the losses incidental to the older process by an amount estimated at \$3,000,000 a year in normal times and perhaps \$10,000,000 a year in war times, besides contributing more healthful working conditions. Such announcements are suggestive of the tremendous latent possibilities in the field of electrometallurgy.

³ The Bureau of Soils of the Department of Agriculture, in cooperation with the R. B. Davis Co., of Hoboken, N. J., has recently conducted important experiments in this field, with results published by J. N. Carothers in the *Journal of Industrial and Engineering Chemistry*, January 8, 1918, and subsequently enlarged upon by W. H. Waggoner and C. R. Wagner in the May, 1918, issue of that journal. It is found that the manufacture of pure phosphoric acid from high-grade phosphate rock at the mines by means of an electric furnace comes to about \$65 a ton of available phosphoric acid, which is some \$12 higher than the cost of an equivalent availability in the form of acid phosphate as conventionally made by treating high-grade phosphate rock with sulphuric acid. But by manufacturing phosphoric acid from mine-run phosphate rock, thus eliminating part of the mining cost (and incidentally greatly enlarging the yield of a deposit), and treating high-grade phosphate rock with the phosphoric acid so produced, a double superphosphate is obtained containing three times as much phosphoric acid as ordinary acid phosphate and at a cost of around \$46 a ton of available phosphoric acid. In the process the item of power amounts to roughly two-thirds of the total

drawn upon and presumably with the help of the electric current.¹ It is scarcely too much to say that the fertilizer industry in the course of a decade or so will undergo a radical change, in which importations of Chilean nitrate, German potash, and Spanish pyrite will be a thing of the past. But the course of progress will depend very much upon the conditions surrounding the supply of electrical power in this country; this matter will determine the speed of advancement and reflect in some measure in this respect upon the cost of living.

In the field of manufacturing, electrochemistry occupies a unique place. It has already created a number of products of fundamental usefulness, while the latent opportunities for the future are very great. The development of artificial abrasives, especially carborundum, superior to natural abrasives, has greatly facilitated many processes of mechanical manufacture, such as the making of automobiles, ordnance, and other materials; the production of calcium carbide has made the acetylene lamp possible, with inestimable benefit to thousands of mines the world over, which have thus been freed from smoky oil lamps and flickering candles; and the manufacture of artificial graphite is rendering a useful service as a lubricant in conserving energy. These products, which are of much greater significance than may be measured by the pecuniary value of the output, have all been developed at Niagara Falls as result of the abundant electric power earlier available there and are made from

cost of the finished product. This goes to show that while under present conditions the process verges on being a commercial proposition, an appreciable reduction in the cost of power, even under post-war conditions of cheaper sulphuric acid, would bring the electric-furnace method into competition with the old acid process. The gain in transportation accruing from the shipment of a commodity of three times the present concentration and the enlargement in the phosphate reserve made possible by bringing into play phosphate rock containing more than 3 to 4 per cent of the combined oxides of iron and aluminum (material not usable in the present acid process) commend the whole matter to careful consideration. It should be remembered, too, that of fertilizing materials phosphoric acid appears to be the only one which, from present knowledge, is absolutely limited in amount and therefore demands unusual care in its utilization.

¹ "With respect to the necessary supplies of plant foods other than nitrogen, it has not as yet been seriously considered to utilize electric power, but, speaking to electrical engineers, I can say that the extraction of potash from feldspathic and granitic rocks by electrolysis presents by no means an insoluble or even, in my opinion, a difficult problem. It is perhaps the easiest way that has been as yet proposed to artificially obtain potash, which only awaits cheap enough power to become a reality. I need only remind you that in the silicate rocks of which our mountain ranges are composed, there lie dormant untold billions of tons of potash, to show that when the proper time comes we will not want for raw material. On this special topic I am well informed, for I have made a close study of it in the laboratory and in the field for many years." (A. S. Cushman, Water-power development and the food problem, Proc. Amer. Inst. Electr. Eng., May, 1916, p. 547.) Since this was written, as noted above, the electric-furnace production of phosphoric acid has almost become a commercial possibility—so rapid is progress in such matters. Also, part of the potash even now being produced in the United States is precipitated from waste fumes from cement plants and blast furnaces by means of the discharge of an electric current. Thus the statement above bids fair to be realized, if not literally, at least through the by-product recovery of potash by means of the electric current.

raw materials of the commonest and cheapest kinds, such as sand, lime, coke, and others. Further products, too numerous to specify, are being commercially launched or are in the experimental stage in the works and laboratories of that electrochemical center. An important industry has also developed in the electrolytic manufacture of sodium and chlorine, and their numerous compounds, used in large quantities in a wide variety of other industries, which are made from common salt—a widespread and cheap material. It would appear that one striking characteristic of electrochemistry is its ability to convert into useful products the commonest and cheapest of everyday materials. It holds forth in this sense the prospect of the highest type of constructive economic service.

On the whole, then, electrochemical industries and applications have developed in the United States to some extent in spite of high electric-power rates, but the lines of development have been those in which the advantages to be gained were conspicuous and the operations have been largely confined to Niagara Falls. In the vaster range of possibilities, in which the opportunities were not so outstanding, high rates and lack of available power have been sufficient to head off an incalculable range of prospective enterprises, to the country's serious economic loss. Indeed, if electric power were made available in quantity at rates half the prevailing tariff, the upgrowth of electrochemical industries would overwhelm the previous attainments along this line.¹

The whole field of electrochemical development in the United States is dependent in the last analysis upon the quantity and price of electric power. And in both respects the power situation as it now stands is inadequate. Unless we are prepared to see the electrochemical industries which we now have emigrate in part to foreign countries, and unless we are also willing to face a stagnant condition in respect to a wide range of important industrial developments, the whole matter of our power supply must come up for attention. This matter does not concern one section or one class; the field is country wide; the outcome concerns both industry and the public interest. And labor in particular will find a concern in this affair, for only by cheapened mechanical power can a generous rate of human compensation be sustained in the face of cheaper labor, both human and mechanical, on the European market.

SUMMARY.

Modern society is dependent upon industrialism, the material framework of civilization.

¹ There is a great stir in the South at present over the prospects of a great electrochemical industry growing up within the reaches of the Government nitrate plants at Muscle Shoals, Alabama. The price of power will, of course, be the critical factor conditioning the outcome.

American industrialism differs from the industrialism of other nations in two respects; it places unusual emphasis upon the employment of power and it couples an advanced industrial development, which means a high standard of living, with a vast expanse of territory.

Each of these conditions imposes a special demand upon transportation, and the two combined have given rise to transportation difficulties that are threatening to throttle the economic life of the country.

If unrelieved the situation will entail a deterioration in the standard of living.¹ The effects of a lowered living scale so caused will not fall evenly the country over, but may be expected to be selective to the disadvantage of unfavored sections, with the setting up of economic discord and sectional dissension in the place of national unity.

The issue can not be adequately met by furthering the development of the railways alone, for already this type of carrier has been pushed to such a point of overdevelopment as to constitute a critical weakness in the economic structure of the country. The source of the disqualification lies not merely in the sheer magnitude of the responsibility which the railways support, but also in their notably inferior elasticity in respect to industrial expansion as compared with the processes of manufacture. The power supply is the chief single contributor to both conditions of default. It not only comprises, mainly in the form of coal, more than one-third of the total freight of the country, but the dependence upon freight-hauled fuel on the part of an expanding industrial activity places an overweight of burden upon transportation by virtue of the fact that coal, raw materials, and finished products represent three additional units of haulage to be reckoned with for every added unit of production.² Hence the logical way to correct the transportation unfitness of this country is to attack the matter through improvement in power usage.

Three principles of transportation underlie industrial growth, and industrial activities in general conform to their prescriptions as a matter of course. These factors are represented in (1) the employment of suitable facilities for the task of transportation, (2) the advance elimination of superfluous weight, and (3) the full utilization of the material transported. These conditions are seen to be the merest common sense; illustrations of conformity with them are on every hand; in the matter of power alone they have been utterly disregarded. In the working out of these principles, national experience has shown (1) that a transportation system of country-

¹ The situation, as a matter of fact, is already displaying its ability in that direction.

² See pages 106, 107 for the necessary qualifications.

wide scope serving a community interest must be of a common-carrier order subject to public oversight—such has been the lesson of the railways; (2) that in the realm of production, which has to do with the advance elimination of superfluous weight, competition is desirable and should be as unhampered as possible; and (3) that in the field of manufacture and consumption the attainment of full utilization stands in need of constructive help, that here competition unaided is incapable of employing to full effect the principle of *multiple production*. Applying these conceptions to power we find that the situation is at fault, because (1) there is no common-carrier system for the transmission of energy, although the development of electricity permits the power materials to be freed of weight at the source and enables the energy of water power to be utilized; (2) the presence of the railways, in the absence of special facilities for electric transmission, has prevented competition from becoming effective in the direction of the advance elimination of weight; and (3) the failure of this country to recognize the principle of multiple production and vitalize its latent force has held private initiative impotent to use fully the energy materials provided.

The righting of the power situation requires (1) the establishment of a comprehensive system of electric transmission lines to be administered as a common-carrier system like the railways. (2) The provision of such a system will necessitate the coordinated growth of central power stations in coal fields and at water-power sites, and in doing so will open to business enterprise a tremendous field of opportunity hitherto closed off from entry, and thus lead to the balanced development of the two major energy resources. (3) The principle of multiple production, recognized and incorporated in national policy, will supplement the additional service gained through the organized employment of the electrical principle; applied to the production of coal-generated electricity, and, through the medium of municipal public utility plants, to the distributive employment of coal, this principle will effectively correlate the recovery of the commodity and energy values, so as ultimately to effect a full saving of the former and an increased gain of the latter, thus permitting a further relative diminution of the amount of fuel calling for transportation in bulky form. The first two points reduce themselves to a single issue, which is purely a business proposition to be handled by a business organization; the third item is more intangible and it is matter of policy, which, therefore, can not be delegated or otherwise handled in objective fashion.

The provision of a common-carrier system of transmission lines, in brief, is the key to the whole problem. Its establishment will remove the retarding influence of high interest rates and antagonistic

misunderstanding that has blocked water-power development, and will afford the point of departure from precedent in favor of coal-field generation of electricity. Owing to the magnitude of the issue and the manifold lines of progress directly at stake, the development will provide a nuclear point for the establishment of a constructive economic policy, needed not merely for the full development of this field but as well for the proper unfoldment of the industrial possibilities of the country in general. As such a policy has not developed in the past because of economic sectionalism growing chiefly out of an unequalized development of the energy resources, the nationalization of industrial opportunity attainable through a balanced development of power supply will clear the path of the main obstruction to unified action.

Thus specific action in respect to establishing a common-carrier system adapted to the power needs of the country will not only go far toward solving the problem of transportation, but it will improve the fuel supply, correct the economic fallacy of drawing upon capital resources while neglectful of income, contribute to the recovery of the values now lost in the consumption of raw coal, lead to an adequate development of electrochemical activities, cut off a needless annual expenditure running well beyond the billion dollar mark, and constitute a potent contribution in the direction of stimulating the upgrowth of a constructive economic policy of national scope attuned to the needs of modern industrial development.

PART IV.

GENERAL SUMMARY.

STATEMENT OF THE ENERGY SITUATION.

Coal, oil, and water power are the principal sources of energy in the United States. Though commonly regarded separately, they really constitute a single resource group which provides the energy essential to modern conditions and contributes commodities of growing importance besides. Two-thirds of the energy extracted is consumed as power in doing the work of industry and transportation, while the balance is devoted to the production of heat and light and to the furtherance of chemical work. The commodity values held in coal and oil, while having an important and growing bearing upon modern needs, are largely ignored. Not only is the industrial, civic, and domestic life of this country utterly dependent upon the energy materials, particularly coal; but the production, transportation, and distribution of these essentials constitutes a prominent aspect of the country's activity. Thus 700,000,000 tons of coal, 350,000,000 barrels of petroleum, and 6,000,000 horsepower of hydroelectricity represent the annual numerical measure of the field; over a third of the freight of the country is coal; the smoke and grime of cities is unburnt fuel; more than a million men are engaged in the mining of coal and oil alone.

The energy supply of the United States has given considerable trouble during 1917-18. This is commonly attributed to the abnormal conditions created by the war. But a careful analysis of the whole situation indicates that all the faults felt acutely during the war were present in the situation before that period, together with others yet to be appreciated. The war produced no new issues in this field. The situation was unsound before the coming of war. A serious fuel shortage affects the country to-day. With the resumption of normal demand, normal labor conditions, and normal railway transportation, this country will still face a critical problem in fuel and power. It is scarcely too much to affirm that the established method of supplying the energy needs of the country has permanently broken down.

Can this country continue to rely almost exclusively upon the railways for its supply of energy? Coal alone now engages nearly half the freight capacity of the railways. Can the cities and homes of the country afford to turn to bituminous coal with its smoke and

dirt for their fuel dependency? Anthracite is fast becoming a luxury. Is the public ready to curtail the use of automobiles and motor transport within the next few years because of the rising cost of gasoline? The petroleum resource is already showing signs of exhaustion. Is it wise for this country to ignore its water-power resources? Under present conditions water-power sites, with choice exceptions, can not be developed. If we are prepared to answer these questions in the affirmative the whole matter may be dismissed. Otherwise, the present situation must come up for revision.

These are the most immediate points of practical contact with the energy problem. They all involve issues of the day—transportation, domestic fuel, motor fuel, water power. But these are not all. What are the civic losses due to smoke? What of the values going to waste when raw coal is burned? Can these be saved and made to contribute to a lowered fuel cost? What are the chances of building up a large coal-products industry in this country? Has chemistry as yet wrested its full count from coal tar? What will we *miss* by not cultivating this field? Can coal solve our nitrogen problem? What are the by-product possibilities in petroleum? What will the far west do for fuel when its oil supply begins to run out? Why is hydroelectric power much cheaper in foreign countries than in the United States? What bearing will this have upon the upgrowth of electrochemical industries? What can we *save* by reconstructing our energy situation? And what can we *gain* in addition to what we save? Can the United States afford to ignore this field in view of what is being done in this direction abroad?

These matters are pressing forward for attention. They are all involved in the single problem of our energy resources. This study has sought to face these questions squarely and to record the answers that the resource group itself provides in the light of modern technological attainments and current economic practice. We have a certain but bountiful measure of material resources; the amount is fairly accurately known. The aggregate of scientific knowledge bearing on the utilization of these resources is considerable; progress here is rapid and the field responds readily to cultivation. The employment of the energy resources is now directed by certain types of economic institutions and procedure; some are satisfactory, others can be made so upon modification. Here are the three factors in the situation—resources, technology, economic procedure. The resources are material things, with limitations fixed by the laws of physics, chemistry, and geology. Technology is a human product, limited only by the genius of man; thus far in the history of the world it has developed largely in response to specific needs; its power as a broad force, to be mobilized and directed to a given end, has scarcely yet been tried; heretofore it has been a tool in the

hands of business enterprise; as an agent for social service, for the common good, its attainments lie chiefly in prospect. Economic procedure is an establishment of precedent; it is the method whereby technology is brought to the development of resources; it tends to become standardized, whereas technology is constantly advancing; it is far more inflexible than technology; in the realm of energy usage it is far out of adjustment with the resource facts and the status of technology. There needs to be better coordination between resources, technology, and economic procedure. The economic procedure whereby energy is brought into play in the United States is mainly a product of a period when the nature of the energy resources were imperfectly known and the technology of energy employment was crudely developed.

The employment of the energy resources involves three progressive stages—production, transportation, and utilization. We may examine coal, oil, and water power in turn in respect to their status under each of these heads.

The production of coal¹ is wasteful because of the abundance of the resource. This has led to excessive competition, overdevelopment of the resource, and the offering of coal at the mine at a price unduly low. Under these circumstances only easy-to-mine coal can be extracted at a profit. In consequence, also, improvements in methods of mining are slow of introduction and means for storing coal have not been developed. The supply of labor is not equal to the capacity of the developed mines, hence a labor shortage always develops in periods of prosperity, when the demand for coal suddenly increases. Since less than 1 per cent of our coal supply has been used, it is hard to arouse any interest in wastes resulting from inadequate methods of coal production.

Transportation is the weakest link in our coal supply. Coal is over a third of the country's freight; the mining of coal is dependent upon an unbroken movement of coal cars past the mine mouths; the number of coal cars has never been equal to the full capacity of the developed coal mines. With every period of industrial prosperity a car shortage is bound to result. Moreover, as result of the size and industrial status of this country, the railways have a sufficient responsibility without the carriage of coal. The haulage of much of the coal represents waste effort since the energy can be extracted in the coal fields and transmitted over wires in the form of electricity.

Present utilization of coal involves a very low recovery of the energy content and an almost total loss of the commodity values present. This, of course, necessitates the production, transportation, and distribution of a much larger quantity than would otherwise be required; concentrates the whole cost, in respect to the consumer,

¹ The statements of this paragraph do not refer to anthracite, the mining of which is satisfactory.

upon the modicum of energy extracted; requires the imports of materials which might be manufactured from the non-energy components; holds back the development of latent possibilities in coal products; besmears with dirt and smoke an untold wealth in civic improvements.¹

The production of petroleum involves a higher proportion of waste than is found in coal mining and with far more serious consequences, because the supply is rapidly approaching exhaustion.

Less than half of the oil underground is raised to the surface, and there is a gross overproduction which prompts the surplus to be wastefully used. The small-unit, competitive methods of mining followed for the most part, are entirely out of adjustment with the occurrence of the resource. The migratory character of oil, under these conditions of exploitation, necessitates a hasty, careless extraction; efficient engineering practice is impossible.

The transportation of petroleum makes use of an extensive system of pipe lines and is satisfactory.

The utilization of petroleum is satisfactory in respect to the portion fully refined; the rest, of course, is devoted to low and wasteful uses to create an outlet for the surplus production. The by-product possibilities held in petroleum have not been sufficiently cultivated. Fuel oil and crude petroleum are used rather extensively in place of coal and hydroelectricity, but this is due to the general overproduction of petroleum which makes this intrinsically more valuable substance a temporary competitor.

Only a small fraction of the water-power resources of the country is developed. This is due to the abundance of coal and oil, on the one hand, and the high rate of interest demanded by capital in respect to hydroelectric developments, on the other, with complications growing out of public sentiment and legal restriction as regards water-power rights under Federal control.

The transportation of hydroelectricity, so far as it is produced, is satisfactory. The lack of a common-carrier system for the transmission of electrical energy contributes to the undevelopment of water-power sites by necessitating the generating project to provide its own transportation. An analogous situation would arise if a coal-mining project had to capitalize a private railway to its market.

The utilization of hydroelectricity is satisfactory. Of course it is underused, to the cost of coal and oil, but that goes back to lack of production.

¹ The Prime Minister of England is quoted as saying: "In times of peace coal is the most important element in the industrial life of the country. In peace and in war King Coal is the paramount lord of industry. It enters into every article of consumption and utility. It is our real international coinage. We buy goods abroad—food and raw material. We pay not in gold, but in coal. In war it is life for us and death for our enemies. It not merely fetches and carries for us, it *makes* the material and the machinery which it transports. It bends, it molds, it fills the weapons of war. Steam means coal. Machine guns mean coal. Cannon mean coal. Shells are made with coal. The very explosives inside them are coal. Then coal carries them right in to the battle field and to help our men. Coal is everything to us and we want more of it to win victory. Coal is the most terrible of our enemies and it is the most potent of friends."

Going over the preceding summary of the energy situation and drawing out the more significant defaults, the points around which center the various more specific troubles, we find that (1) there is excessive competition in coal mining; (2) inadequate transportation is provided for coal; (3) the distributive manner in which coal is used involves too much inconvenience and waste, especially for the domestic consumer; (4) the economics of oil mining is out of adjustment with oil occurrence; (5) water power is underdeveloped because of the financial status of power-site developments. In attempting to bring the whole complicated energy situation down to a few, concrete, practical issues which may find attachment to our current machinery of national administration, we may set to one side the matter of coal production. Not that this is unimportant, but the other matters are more immediately important and may gain in popularity by being thus divorced from an item, the correction of which might involve a step that this country may not yet be prepared to take. Moreover, coal production may be improved indirectly through provisions in respect to transportation and utilization. It were better, then, that the four more immediate issues should stand together and apart from the matter of coal conservation.

Looking at the situation reduced to these heads, we find that coal and water power overlap in respect to the provisions of industrial energy (i.e., power), leaving a portion of the coal to apply to domestic needs under the head of domestic fuel; while oil, by virtue of its specialized service, still stands apart as distinctive, though not wholly unmeshed from the general situation. Thus the default of coal in respect to transportation and the default of water power in respect to production are fundamentally parts of a single issue concerned with the supply of industrial power; the wastes in the utilization of coal concern primarily the domestic consumer and his methods of employing fuel; the inadequacy in oil remains still a matter of improper production. These three issues are believed to lie at the base of the entire energy situation. If we set aright the power supply through a proper development of water power and the provision of adequate transportation for coal, arrange for an economical supply of smokeless fuel for domestic use, and correct the glaring wastes in respect to petroleum growing out of the present methods of production, we will have taken the most important steps essential to the proper functioning of our energy resources.

PROBLEM OF POWER SUPPLY.

Under present conditions the power supply of the country is provided chiefly in the form of coal, with fuel oil the mainstay in sections distant from coal fields, and water power drawn upon

here and there where conditions are favorable to its development. The coal applied to the production of power amounts to a half billion tons, and is hauled chiefly by the railways to its multitudinous points of use, although as much as a quarter of the supply is in many instances there turned into electric power. This method of using coal power imposes a tremendous burden upon the railways, leading to congestion and shortages in periods of business prosperity when the demand for coal enlarges and the amount of other materials claiming transportation at the same time increases. The use of fuel oil and crude petroleum for purposes of steam raising and the like, which is considerable and represents over half of the total consumption of petroleum and its products in point of bulk, sustains a gross overproduction of petroleum, and in consequence contributes markedly to a premature exhaustion of the resource, with initial effects already in sight. The relative lack of employment of water power adds to the overburden falling upon transportation in respect to coal, not to mention its bearing upon the portion of coal and oil used to support the delinquency on the side of water power. It, moreover, leads to an unnecessary centralization of industry with undue differentiation of economic interest, as is apparent in view of the complementary distribution of coal and water power.

Industrialism has grown up upon the basis of the distributive use of coal. The economics of the situation rests in this status, although the technology of power usage has advanced beyond this state. Power stations centralized in respect to the coal fields and distributing electrical energy to the points of utilization represent the most economical method of coal-power usage. Apparently such a development has not promised to be profitable to private enterprise, otherwise we would have it. The development is technologically feasible. The lack is due to the fact that the common-carrier systems of the country are equipped for carrying *coal*, not for carrying *energy*. Hence industrial enterprises find it more profitable to purchase coal hauled by the railways than to provide themselves with special facilities for the transmission of electricity. The railways, also, have not gone into the matter; hauling coal has been one of their most important and profitable items of freight, which they have been loath to give up; moreover, they have been subjected to a type of Federal control in respect to rates such as would make them stand to lose the benefits of economies in this direction.

Although hindered by legal restrictions growing out of a public sentiment that disfavored any action savoring of commercialization in respect to scenic beauty, water power has not developed because of the high cost of money demanded by current financial conditions for water-power projects. Since three-fourths of the running expenses of a hydro-electric plant is interest money on the

heavy investment consequent to development, an interest rate of 8 to 10 per cent as obtaining in the United States places water power above competition with coal and oil under their present circumstances of overproduction and cheap supply. Such power sites as have developed, aside from those initiated by the Government under war conditions, have been choice examples with such natural advantages of topography and location as to offset the financial handicap. With no change in financial status, water power can not develop until coal and oil are skimmed of their cream. In the case of oil, this is impending, and in the far West but a few years distant, there merely waiting upon the decline of the California oil fields.

The provision of a common-carrier system for the transmission of electricity will remove the factor now retarding the generation of carboelectricity¹ in coal fields. It will also relieve hydroelectricity of part of its development expense² and also reflect a degree of stability upon hydroelectric projects that will secure for them an interest rate comparable with that under which the railways are financed—namely, 5 to 6 per cent instead of 8 to 10 per cent. This will bring a considerable addition of water power into competition with coal and oil.

As the main default in our present system of power usage is transportation, and both carboelectricity and hydroelectricity can be remedied through an improvement in transportation, the furtherance of this matter attaches itself to the administration which has railway transportation in hand. The ultimate status of the matter will fare alike with the ultimate status of the railways. But at present, a special business organization for undertaking this special activity is desirable, to be brought into being by the Government, ultimately to be either under Federal ownership or else under private control with Federal oversight, as the outcome of the railways may dictate. The Federal backing, in either event, will give the requisite standing and stability to create the public confidence essential to the success of the enterprise. The organization charged with this matter will naturally confine its operations to the transportation of energy, but as this development will open to business enterprise a large and favorable field in the production of carboelectricity and hydroelectricity, it may fairly exercise a measure of oversight over the operations of these various producing units to the extent of insuring a balanced, coordinated upgrowth and effective operation of the whole matter, at the same time avoiding the imposition of any restrictions which might curtail private initiative and enterprise. In this sense, also, the central organization would find an interest in facilitating the by-product consumption of coal in

¹ Electricity generated from coal, as opposed to hydroelectricity as generated from water power.

² Under present conditions the transmission line is part of the hydroelectric development.

the central generating stations using coal. This would come about naturally, however, for a central power station established under present conditions would find it profitable to consider by-product practice. As the inability to dispose advantageously of the surplus gas, in the case of coke manufacture, has been the chief retarding influence disfavoring the introduction of the by-product coke oven, the gasification of coal, with attendant recovery of ammonia, benzol, and tar, and the employment of gas engines or gas turbines, would probably represent the line of action to be followed by private enterprise in entering upon the field as here outlined.

In brief, the attachment of the power problem to the transportation issue, where it belongs, will lead to the provision of a common-carrier system of electric transmission lines national in scope, and this in turn will involve the balanced and economical development of the coal and water-power resources of the country. The relief to transportation that such a development would bring would be great and far-reaching. In addition to this direct saving, there would accrue the gain in the values now lost, in the upgrowth of electrochemistry with its tremendous possibilities; and, by no means least, a diffusion of industrial opportunity such as would make for a more healthy industrial life and a unity of economic interest which would contribute notably to the welfare of the Nation.¹

PROBLEM OF DOMESTIC FUEL.

Even with a complete readjustment of the power supply, it will still be necessary to transport a considerable amount of coal for small industrial users out of touch with the transmission lines and for domestic use. Leaving aside the first of these as representing a utilization so scattering as to be outside a practical plan for improvement, there remains a domestic-fuel consumption that runs something over a hundred million tons a year. This item presents a distinct problem. Thus far anthracite, which is smokeless, has been the fuel dependency of the American home. But anthracite comes only from a small area in Pennsylvania. Bituminous coal has already been forced to take its place in the more distant States, and the growing price of anthracite, which is mounting along with the gradual depletion of deposits limited in size, is fast forcing this high-grade coal

¹At the annual meeting of the Association of the Chambers of Commerce of the United Kingdom, held in London on April 9 and 10, 1918, the following resolution was adopted in regard to the development of power in England:

"That this association recognizing the urgent necessity to increase the productivity of our industries after the war, as the chief means to meet the burden of the war debt of the Nation and to maintain high wages for the workers, urges His Majesty's Government—

"(a) To recognize that the public supply of electrical energy for power, light, traction, heat, electrochemical and other purposes as a key industry in so much that all other industries are becoming increasingly dependent upon it.

"(b) To hasten the amendment of the legislation which has hitherto hampered its efficient development.

"(c) To insure the supply at the earliest possible date of an ample and cheap supply of electricity for all purposes.

"(d) To conserve our coal resources, the chief natural wealth of the country, by compelling the exercise of the maximum possible economy in its use for industrial, domestic, and all other purposes."

into the realm of a luxury. The homes of the country, therefore, must look to a dependence upon bituminous coal. There is no alternative.

But the dense smoke of bituminous coal is intolerable in view of the efforts going into civic improvements, which would come to nothing in event of widespread use of this dirty fuel. The trouble can not be corrected by the individual consumer; either the coal must be treated by a community operation or smoky cities must be put up with. It so happens, however, that coal smoke contains materials of great and growing commercial value. Hence, if coal can be treated on a large scale, the by-product values represented in the smoke will support the operation and give a smokeless fuel at a cost less than the present price of anthracite. It is technically possible to treat bituminous coal in large quantities so as to yield smokeless fuel, ammonia, benzol, and tar. The smokeless fuel can be recovered entirely in the form of gas, or else in the form of a solid artificial anthracite together with a smaller production of gas. The by-products have value for direct uses and form the starting point for the manufacture of valuable chemical products, as dyes, drugs, and fertilizers. On the basis of 1915 prices, a ton of coal which sold at the mines at slightly more than \$1 contained values adding up to over \$14. With this discrepancy between value realized and value attainable, it is believed that the technological possibility is likewise an economic possibility. Indeed, the present use of raw bituminous coal in homes is an anachronism.

The lack of progress in domestic fuel is influenced by habit and by the relatively abundant supply of anthracite heretofore available, but more fundamentally advance has been blocked by the virtual failure of public utilities in American municipal life. Had the public utilities function been soundly developed in the United States, the fuel needs of each community would now be served by public service corporations, at a saving to the community over the aggregate cost of its fuel under present conditions and at a great gain to the community in cleanliness and health.

As the default is laid at the doors of public utilities, it is desirable to examine more specifically wherein this type of activity has fallen down; for it is obvious that if domestic fuel has not adequately developed because of a flaw in public utilities administration, it can not be expected to develop adequately until this defect has been set aright. A public utility may be defined as a necessity in general use which does not lend itself to competition. This conception has been accepted for certain community essentials like water-supply, gas-supply, traction service, and the like. It is commonly recognized that the activities falling under such heads can not be entrusted to the unrestricted competition of business enterprise.

But this recognition has been a matter of growth, not at all a sudden appreciation of the case. Looking merely at the main steps in the evolution of the public utility conception, we see that the distinctiveness of the field first met formal recognition upon the insertion of certain clauses into municipal franchises, imposing in advance the restrictions deemed necessary in return for the privileges extended. This course of action clearly established a field of operations that differed from the setting accorded industrial activities in general; public participation in industrial affairs thus had its inception. But, inside the restrictions agreed upon in advance, the operating company had the utmost freedom in regard to procedure, profits, and the like; under these conditions a public service organization still had incentive for advancing its practice and otherwise increasing its efficiency. This method of administration, however, while lucrative to private enterprise, proved a failure from a public-service viewpoint, due, in the main, to the corruptibility of municipal authorities. This régime covers a dark page in American municipal government.

Following the failure of franchise control of public utilities, another step in the direction of furthered public oversight was added in the form of public utilities commissions; this method of control has come extensively into vogue and its sphere of influence is spreading. The public utilities commission carries public oversight from its initiation in the franchise over into the actual operations of the activity concerned. This method of administration, for which American municipalities have held high hopes, has likewise failed. It has succeeded in removing the incentive for progress, which was still present under the franchise régime, without supplying any activating influence in its stead. It insures in favor of the public for the full gain of any increased efficiency that may come into play, but in so doing it removes the industrial motive that makes for increased efficiency. While protecting the public from the appearance of gross extortion, at the same time it shields the public from gaining the advantages of technological advance. It puts a premium on stagnation; it defeats the purpose for which it was created.¹ In the course of American industrial evolution, just in proportion as successive activities have come under our present type of public utility control, to the same extent have efficiency and progressiveness fallen into abeyance. This is illustrated on the one hand by the gas works, one of the earliest public utilities to come under the present type of control and hence notorious for its inadequate practice; and, on the other, by the telephone service, scarcely yet affected by public oversight and in consequence still highly efficient. Adequacy

¹ This is aside from the matter of integrity and wisdom on the part of the personnel of the commission. No public utility organization can count on gaining anything worth while by lowering its operating costs, because of a proportionate reduction in rates which will be demanded.

in industrial affairs seems to be in inverse ratio to the degree of public oversight extended over them.

If this is the case, what then is the answer? The public utilities can not be turned back into private hands; yet the entrance of public oversight into their administration is a withering influence, tending to set up ineffectiveness. There would appear to be no middle ground. The lesson of experience seems to say: Either go all the way in or stay out. Those public utilities under public ownership are effective: Witness the United States Post Office and the National Forests. Private industries are effective: See the industrial primacy of this country. Only those compromise activities, neither the one nor the other, are conspicuously faulty.

If it is true, then, that public participation in the conduct of business affairs exerts a withering influence, as seems to be unmistakably evidenced in the case of the general run of public utility activities, there arises a grave question as to the outcome of the current Federal control of industry, entered upon as a war measure and designed as a temporary expedient. While these measures, for the most part, will doubtless be laid aside according to schedule, it is a fair presumption that their emergency use will raise a significant call for an increased degree of Federal industrial control as a permanent establishment. In anticipation of such an issue it is desirable to draw the line sharply between (1) the great majority of industrial activities which require the utmost freedom for effective advancement, and (2) the relatively limited range of activities covering necessities in general use that do not lend themselves to competition, or, in other words, the field of public utilities, whose evolutionary end-point is public ownership. A failure on the part of the public to draw the line of demarkation short of private industry, or an unwillingness on the part of private industry to concede to full public control the region falling clearly under the heading of public utilities, will lead to a disastrous confusion harmful to the welfare of industrial enterprise and the public interest, and that is to say, of the nation as a whole. An adequate public utilities conception will be a safeguard badly needed in the period of reconstruction to follow the coming of peace. To this end, the opportunity of clearing up the matter of public utilities through the furtherance of the domestic-fuel issue holds an importance which should not be overlooked.

Throughout this analysis the purpose has been to seek improvement through the means in hand—through stimulated evolution rather than enforced reconstruction. From this point of view we see that the fuel problem calls for central municipal plants, administered as public utilities, which will provide the fuel needs of the community along modern lines. Looking over the field, we observe that the municipal

gas plant, present in all cities, is the nearest approach to the needs of the situation; although under present conditions such plants provide only a small fraction of the community needs and furnish even that fraction in an obsolete manner and at an excessive price. Such gas plants are the logical points of attachment for the upgrowth of municipal by-product fuel plants. We may infer that the gas plants have not as yet gone into this larger field of fuel service because of their anomalous position, being neither private enterprise nor public enterprise, having their incentive for improvement removed by the public with no activating motive substituted in its place.

But it is not the function of this paper to linger over the matter of public utilities longer than to emphasize the obstacle that the present type of administration interposes in the way of fuel progress. But even accepting a lame horse, there may still be hope of progress; indeed, exercise in the direction of progress may be just the thing to bring the whole public utility conception into good health. If so, the gain would be immeasurable, for few other outcomes are so necessary to the welfare of the common run of men. So, even as the matter stands, the situation has considerable possibilities if the organization concerned with the transportation of energy will serve as a coordinating influence, in recognition of the fact that domestic fuel is an integral part of the energy problem as a whole. Domestic fuel, in point of fact, concerns transportation directly, for proper utilization through increased recovery of energy will cut down one-half or more the carriage of the coal involved. Moreover, full utilization, whether at the distributive points or at the production centers, needs to be brought to a common basis of practice and effectiveness. Besides, the provision of an adequate municipal fuel supply would of necessity serve an attendant fringe of gas-fired industries, thus necessitating a balance against the type of electrical service also brought into the community under the auspices of a common-carrier system. Hence, on several counts, the central transportation administration becomes the logical overseer of this pendant activity.¹

The energy-transmission organization may quite appropriately assume the duty of stimulating municipalities toward attaching a centralized fuel service to their gas manufacture. Under the present régime municipalities have no standards against which they can measure the attainments of their public utilities, no means of knowing what correct practice is, nor what is now attainable. The central organization can provide this standard, which can be made to serve in lieu of the competitive spur which holds business enterprise in the line of progress. In this respect the central organization will (a) establish a model plant to demonstrate what can be accomplished,

¹ If the power problem is left in abeyance, the domestic fuel matter may still progress, though less rapidly, through the stimulus of a more specific activity.

(b) cooperate with municipal enterprises to duplicate this model, and (c) keep track of the situation the country over, and in general serve as a clearing house for the balanced advancement of the whole matter. In general the by-products turned out will find a ready market, but their disposition may be enhanced by a constructive program looking toward a proportionated development of those various industries which carry forward the first products into a diverging series of refinements. In a word, this organization will be in a position to lend its influence to a constructive use of the principle of multiple production. The time is so ripe for the full utilization of coal that there would seem to be wanting merely the central agency, such as has been sketched above, to set the whole thing in motion. Not only would the gain accrue to fuel, but in this way a new standard would be set for the public utilities in general.¹

PROBLEM OF OIL.

Petroleum presents an entirely different problem from coal and water power. The issue is technically more complicated than is the case with its two companions, because of the fact that most of the petroleum is subjected to various degrees of refining and hence brought into use in the form of a number of products of varying importance and value. These products are gasoline, kerosene, fuel oil, lubricating oil, and a group of by-products. The utilization of petroleum involves considerable waste, for the total output is not turned into the most valuable range of products attainable. This is due to the fact that production is far in excess of the demand for high-use products. The wastes in utilization go back, then, to the fact that there is a gross overproduction of the crude product. This overproduction results from the small-unit competitive type of mining in vogue in the United States, whereby the geologic unit or pool is divided arbitrarily into many small holdings separated by vertical boundary planes. Petroleum is a migratory mineral moving underground in the direction of lowered pressure; hence each individual producer is forced to race with his neighbor for the extraction of the product. This type of procedure is the inevitable result of such circumstances, and not only contributes an output far in excess of what is legitimately needed, therefore causing the surplus to be used in lieu of coal and water power, but it also contributes to the practical destruction of a large proportion of the oil underground so as to put it out of reach of future recovery. The total losses underground, in handling and in utilization, are estimated to run up to 90 per cent of the resource.

¹ It would appear that this matter would also enlist the active interest and cooperation of the Chamber of Commerce of the United States of America.

This small resource-recovery takes on importance in view of the fact that the unmined reserve of petroleum is very small—about 70 barrels to each person, little over fifteen years supply at the present rate of consumption. This is especially significant because of the growing importance of the automotive activity and the fact that the world's machinery is lubricated by oil.

In the normal course of events the maladjustment between the method of exploitation and geological occurrence will straighten itself out, but only at the expense of much of the resource, and in response to a mounting value of the product, which will ultimately react to insure proper production. But petroleum is too essential for the country to await this time without effort to improve matters.

Part of the petroleum resource is still under Federal ownership on public lands, and in respect to this the Government can insure proper exploitation by the enactment of proper legislation providing for the elimination of the discordance between occurrence and method of production. Legislation is now pending regarding the public oil lands, but the true nature of the issue is not met therein.

In respect to the oil lands in private hands, the Federal Government has no such direct jurisdiction. But it may be said that the whole Federal policy thus far, so far as the attitude to date may be termed a policy, has been in opposition to an integrative trend in oil production, and hence has retarded progress. For the most part the large agencies in the oil business do not engage primarily in oil production, but purchase their oil from a thousand and one individual producers who do the exploration and drilling and stand for the gains or losses under this head as the case may be. Improvement in this situation may be hastened by a proper attitude toward integrated production. Recognition of the necessity for integration in oil production will go far toward insuring progress, even if no specific legislative means are worked out for pressing the issue further.

A larger-scale type of production financially affiliated with transportation and refining activities will hold the oil under ground until needed for the production of motor-fuel, lubricating oil, and by-products; and such a procedure will set aright the whole situation, thus bringing about a longer resource life, turning the products to their highest uses, and leading to a significant development of the by-product values still imperfectly drawn from the crude material.

CONCLUSION.

As a final summary expression, the main issues in the entire situation may be brought together in a tabular view, as follows:

Tabular analysis of the energy situation (all details and qualifications omitted).

The principal resources.	Coal; oil; water-power.		
The main problems....	Power { Coal power..... Water power..... }	Domestic fuel { Smokeless solid fuel, Gas..... }	Motor fuel.
The main inadequacies.	Transportation.....	Utilization.....	Production.
What is wrong.....	Transportation facilities suitable only for hauling coal.	Wasteful utilization due to improper public utilities development.	High resource waste due to lack of adjustment between method of petroleum mining and geological occurrence.
What is needed.....	A common-carrier system of electric transmission lines.	Municipal public utility fuel plants, with by-product practice, under the coordinating influence of the common-carrier organization aforementioned.	Proper legislation and application of constructive economic policy.
Social gains.....	Balanced development of coal and water power. Relief to transportation. Cheapened electric power. Upgrowth of electrochemical industries. Contribution of fertilizers and other coal products. Contribution to solution of nitrogen problem. Contribution to lowered cost of living. Nationalization of industrial opportunity.	Elimination of smoke from cities. Elimination of waste. Contribution to fertilizer and coal-products industries. Reduction in cost of living. Contribution to solution of nitrogen problem. Improvement in public utilities effectiveness.	Increased supply of motor fuel from limited resource. Elimination of unjustifiable wastes. Maintenance of cheap motor fuel. Prolonged supply of lubricants. Postponement of petroleum exhaustion. Development of by-products.
Financial gain.....	Economies and new sources of income adequate to offset, in large part, the expense of the war.		

In short, the whole energy situation, while extremely complicated, reduces itself to a fundamental basis in which two courses of action on the part of the Government will bring about the proper development of the whole matter. (1) The provision of a common-carrier system for the transmission of electrical energy will (a) lead to a balanced development of coal power and water power and (b) serve as a coordinating influence in the building up of municipal public utility fuel plants. (2) The application of a constructive economic policy to the conditions surrounding the production of petroleum will largely correct the circumstances that are now hastening a premature exhaustion of the petroleum resource. The adoption of the first line of action will involve a recognition of the importance of the energy problem such as will throw sufficient publicity upon petroleum

production to insure revision here that will set petroleum aright. So the focal point of the entire situation is transportation; energy transmission, with all that entails, provides the key to the vast range of possibilities awaiting the coordinated, scientific development of coal, oil, and water power.

The procedure, to repeat, is through the agency of transportation. The tools with which this agency will work are the principle of electricity and the principle of multiple production—both modern forces unknown to the old order, neither cultivated as yet to constructive ends. The directed employment of these forces may be made to indicate the power of modern technical knowledge so clearly as to create, through enlightened public opinion, a constructive economic policy which may not only stem a wholly unwarranted drain on petroleum, the country's most limited resource, but also shape the whole industrial growth of the Nation into the channels of most effective progress.

In conclusion, the pivotal importance of the energy resources can not be emphasized too strongly. They are what they appear to be, and very much more besides. They provide the energy from which modern civilization draws its very existence; they involve the supply of fertilizers, upon which an adequate food supply is dependent; they furnish raw materials for the production of an enlarging series of commodities, without which a nation is helpless in the struggle for existence. The time has passed when an adequate endowment in energy materials is sufficient; the energy resources must now be brought to their highest point of effectiveness. This matter is too near the bottom of things to be neglected. It can not be neglected. A nation which fails at this point will pass.

PUBLICATIONS OF THE DIVISION OF MINERAL TECHNOLOGY,
U. S. NATIONAL MUSEUM.

Publication 2421, Smithsonian Institution. Sources of nitrogen compounds in the United States, by Chester G. Gilbert. Issued June 30, 1916. 12 pp.

Nitrogenous compounds are essential not only to self-defense but to the country's capacity for self-support, and to be effective the source must be such that the products may be adaptable to meet either requirement. This paper reviews the merits of the three principal processes for manufacturing nitrogen compounds from the atmosphere, with the following conclusion: The arc method has not thus far demonstrated capacity to meet the agricultural requirement at all, or even the defense requirement efficiently. Definite knowledge concerning the Haber process is lacking, but its record of achievement is against it, and it would seem, moreover, unsuited to American conditions, at least in the present state of its development. The cyanamid process is capable of a development which will meet the requirements for a cheapened nitrogenous fertilizer source whose form of nitrogen content is readily convertible to nitric acid. The process is already a prominent factor in the economic well-being of most countries of older civilization and is capable of similar extension in the United States.

Bulletin 102, part 1. Coal products: An object lesson in resource administration, by Chester G. Gilbert. Issued November 17, 1917. 16 pp., 11 pls.

The chemical industries of this country are notoriously weak; in fact, up to the outbreak of the present war we had relatively few chemical industries, yet no field of industrial activity is more essential to the country. The most important of all the chemical industries is that represented in the manufacture of coal products. The purpose of this paper is to bring out the reason for the lack of the chemical industries in general and the coal products one in particular, with a view to determining where the fault lies and what should be done to correct it.

Bulletin 102, part 2. Fertilizers: An interpretation of the situation in the United States, by Joseph E. Pogue. Issued October 10, 1917. 22 pp., 1 pl.

The fertilizer resources of the United States are viewed in the light of their importance under war-time conditions, when, on the one hand, an increasing supply is needed for the production of an added output of foodstuffs, and, on the other, the foreign sources of supply from which much of our mineral fertilizer is drawn have been cut off or endangered. The rather remarkable circumstance that this country has been dependent upon Chile for nitrogen, upon Germany for potash, and upon Spain for pyrite used in the manufacture of sulphuric acid, is pointed out in respect to developing national independence as regards these fundamental materials. The paper is accompanied by a chart which shows in one expanse the whole fertilizer situation, with particular regard to the effects of the war upon it. The purpose of the paper is to emphasize to the general public as well as to those more directly interested in fertilizers the importance of dealing with this matter as a broad and fundamental problem affecting the basic matter of food supply.

Bulletin 102, part 3. Sulphur: An example of industrial independence, by Joseph E. Pogue. Issued November 7, 1917. 10 pp., 1 fig., 3 pls.

Two sulphur deposits near the Gulf coast in Louisiana and Texas, worked by an ingenious and efficient mechanical process, not only are supplying practically all of the crude sulphur in this country, but their development has shifted the world's largest sulphur industry from Sicily to the United States. The geological occurrence and method of working the Gulf deposits by means of the Frasch process are described in nontechnical language. The bearing of these deposits on the sulphuric acid situation is discussed and the need pointed out for a determination of the sulphur resources present in the whole Gulf region, with a view to defining a proper adjustment between the needs of the sulphur industry and the sulphuric acid industry.

Bulletin 102, part 4. Coal: The resource and its full utilization, by Chester G. Gilbert and Joseph E. Pogue. Issued February 21, 1918. 26 pp.

The cost of fuel in the home is roughly four or five times the first cost at the mine. In other words, the cost to the consumer is out of all proportion to the price at the producing end. This discrepancy means an extravagant price for fuel in the home and is due to wastefulness of economic procedure all the way down the line between production and consumption. It is the purpose of this paper to analyze the situation and point out economic changes needed to better conditions.

Bulletin 102, part 5. Power: Its significance and needs, by Chester G. Gilbert and Joseph E. Pogue. Issued September 21, 1918.

In this country tremendous emphasis is placed on the use of power; the result is a growing burden on transportation which must be solved. The present transportation difficulty is in a measure an expression of this problem. The purpose of this paper is to develop the general nature of the situation and suggest the character of remedial action called for.

Bulletin 102, part 6. Petroleum: A resource interpretation, by Chester G. Gilbert and Joseph E. Pogue. Issued August 7, 1918. 74 pp., 12 figs., 3 pls.

Petroleum is of particular significance because, of all our important resources, it is most limited and involves the highest percentage of waste. Scarcely one-tenth of the value of the resource is recovered under present circumstances, while the unmined supply available under current practice is only about 70 barrels to each person. This paper makes an economic study of the resource and the industry engaged in its development, and traces the causes of waste to certain maladjustments in the economic situation, pointing out how these may be remedied by a constructive economic policy applied to the matter. The desirability of developing shale oil to replace petroleum as it becomes incapable of meeting the demand is gone into and the advisability of using benzol and alcohol as substitutes for gasoline is considered. The natural gas industry is also treated.

Bulletin 102, part 7. Natural Gas: Its production, service, and conservation, by Samuel S. Wyer. Issued December 28, 1918.

Bulletin 102, vol. 1. The energy resources of the United States: A field for reconstruction, by Chester G. Gilbert and Joseph E. Pogue.

This paper brings together the substance of parts 4, 5, and 6 of Bulletin 102, together with an introduction and a conclusion that coordinate the details of the discussion and draw forth the main issues. It is concluded that the whole matter involves

the threefold problem of fuel supply, power supply, and transportation, and that the entire field may be cleared by (1) providing a common-carrier system of electric transmission lines which will (*a*) lead to a balanced development of coal-power and water-power, and (*b*) serve as a coordinating influence in stimulating by-product recovery from coal in central power stations, and especially in municipal, public utility fuel plants; and (2) applying a constructive economic policy and appropriate legislation to the conditions surrounding petroleum production so as to bring the method of production into conformance with the geological occurrence of the resource. It is believed that these measures would effect economies offsetting, in large part, the cost of the war.

NOTE.—The papers listed above as parts of Bulletin 102 are members of a series entitled "The Mineral Industries of the United States."

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